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**Kim**

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(54) **VERTICAL SEMICONDUCTOR DEVICE AND METHOD FOR FABRICATING THE SAME**

23/53271; H01L 23/53295; H01L 29/0847; H01L 29/40117; H01L 29/66833; H01L 29/792; H01L 27/11582; H01L 27/11568; H01L 27/11578; H01L 27/11575; H01L 27/11524; H01L 27/11529; H01L 27/1157

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See application file for complete search history.

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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*Primary Examiner* — Jonathan Han

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**H01L 21/28** (2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ..... **H10B 43/27** (2023.02); **H01L 23/5226** (2013.01); **H01L 23/53271** (2013.01);

(Continued)

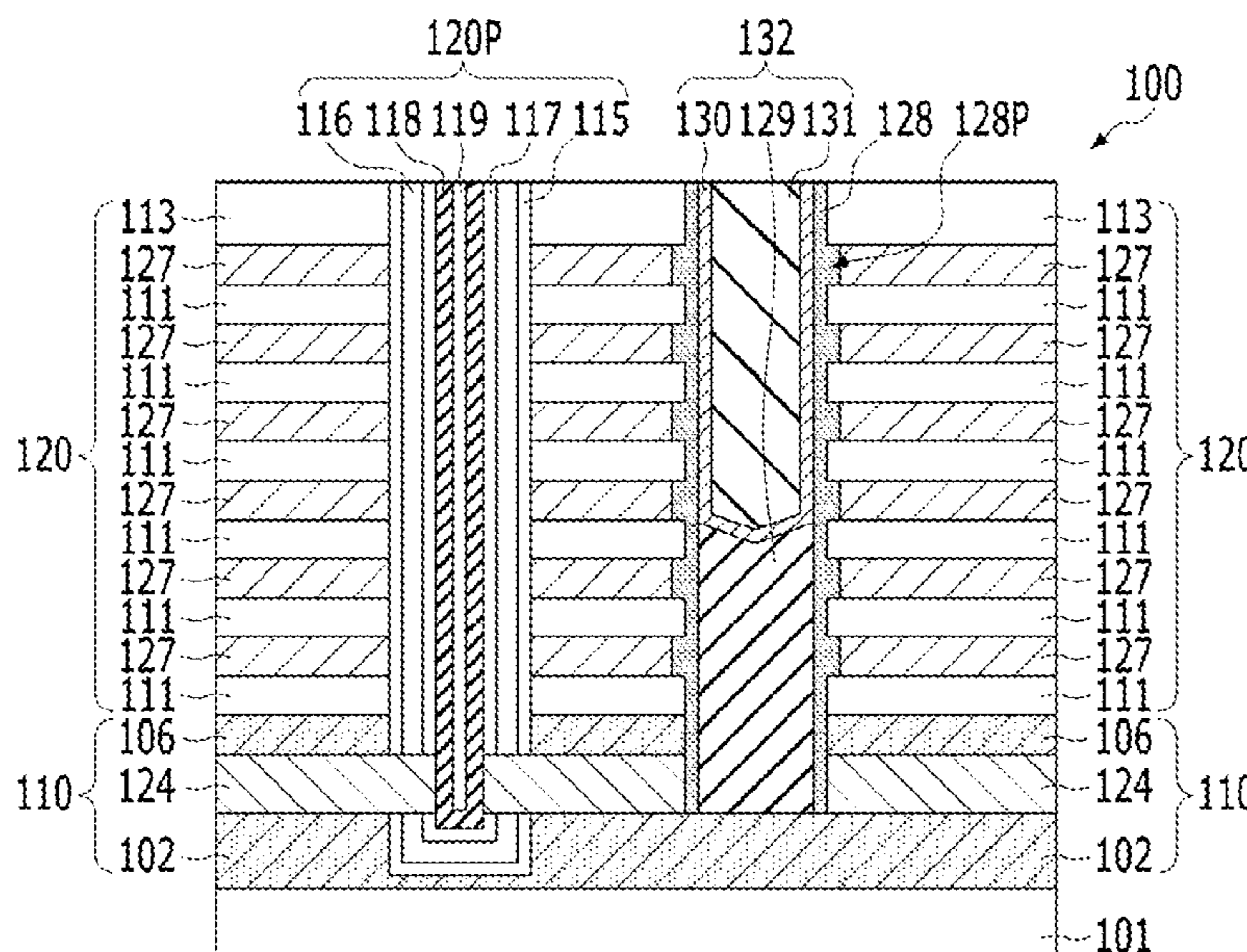
(58) **Field of Classification Search**

CPC ..... H10B 43/27; H10B 43/20; H10B 43/30; H10B 43/50; H01L 23/5226; H01L

(57) **ABSTRACT**

A method for fabricating a semiconductor device includes: forming a first multi-layer stack including liner layers and a source sacrificial layer over a lower structure; forming a second multi-layer stack including dielectric layers and sacrificial layers over the first multi-layer stack; forming a vertical contact recess extending through the second multi-layer stack and the source sacrificial layer; replacing the source sacrificial layer with a source contact layer; forming a carbon-containing spacer on sidewall of the vertical contact recess; replacing the sacrificial layers with conductive layers; and forming a source contact plug in the vertical contact recess.

**14 Claims, 14 Drawing Sheets**



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## Related U.S. Application Data

continuation of application No. 16/842,141, filed on Apr. 7, 2020, now Pat. No. 11,271,008.

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*H01L 23/532* (2006.01)

*H01L 29/08* (2006.01)

(52) **U.S. Cl.**

CPC .... *H01L 23/53295* (2013.01); *H01L 29/0847* (2013.01); *H01L 29/40117* (2019.08)

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FIG. 1

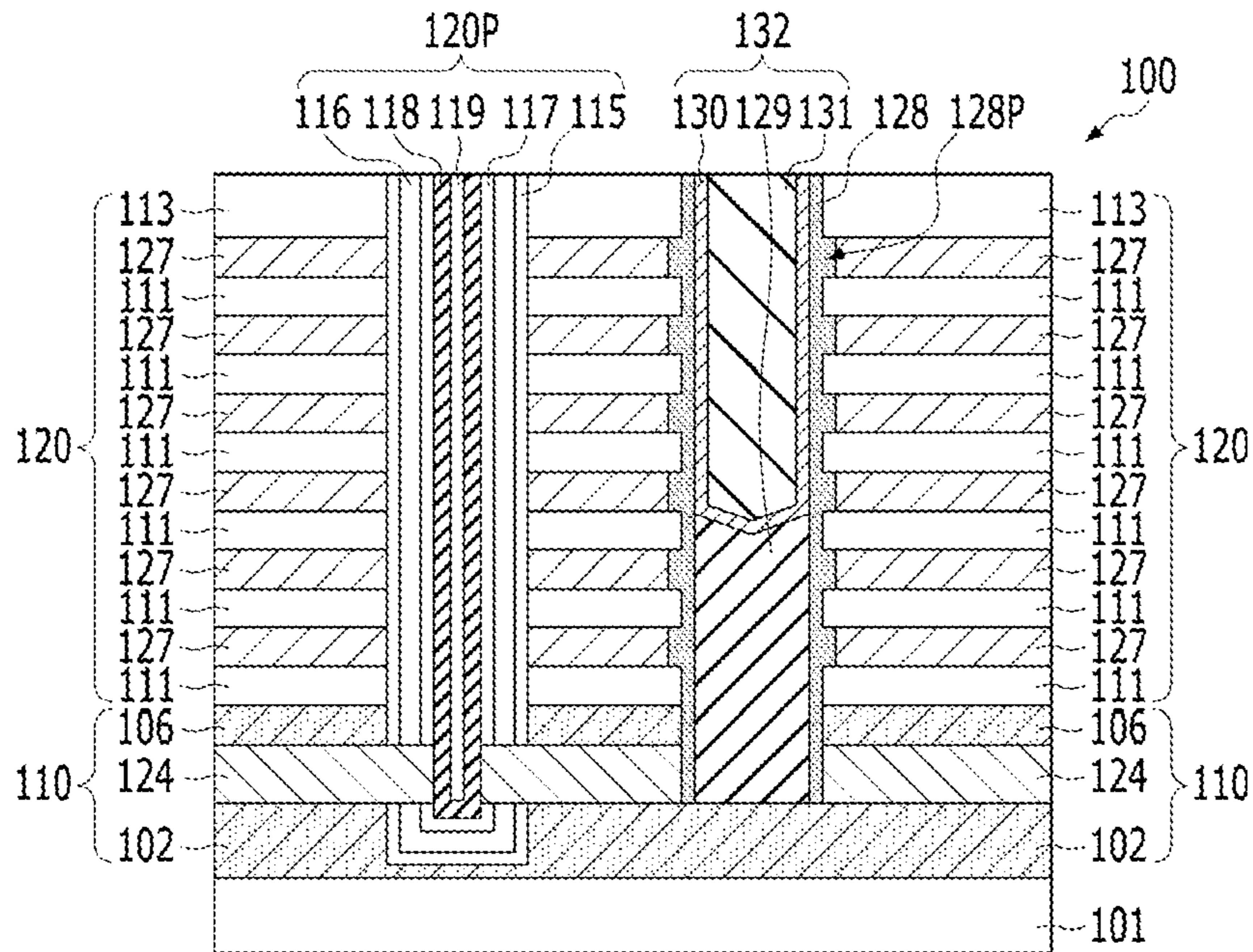


FIG. 2

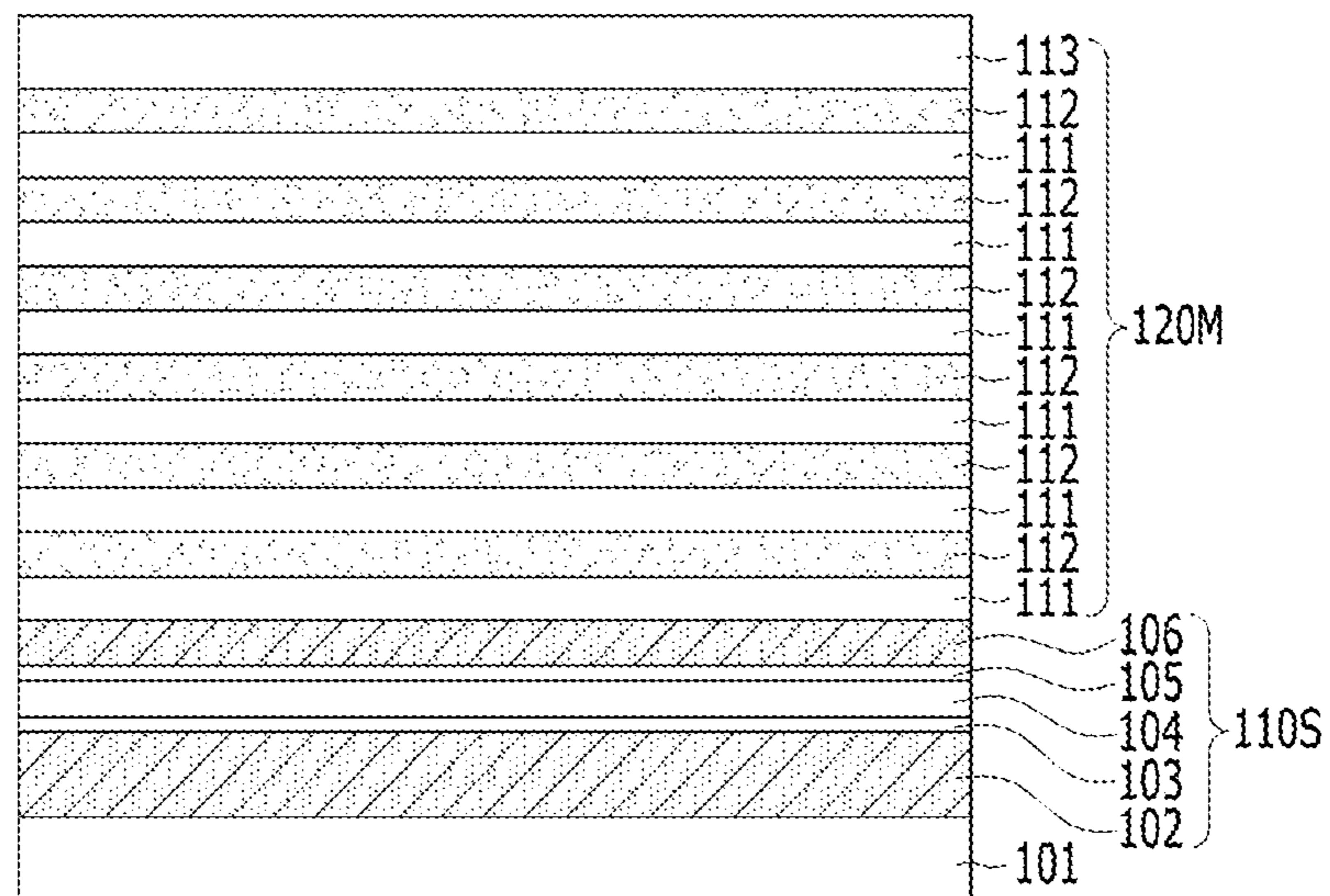


FIG. 3

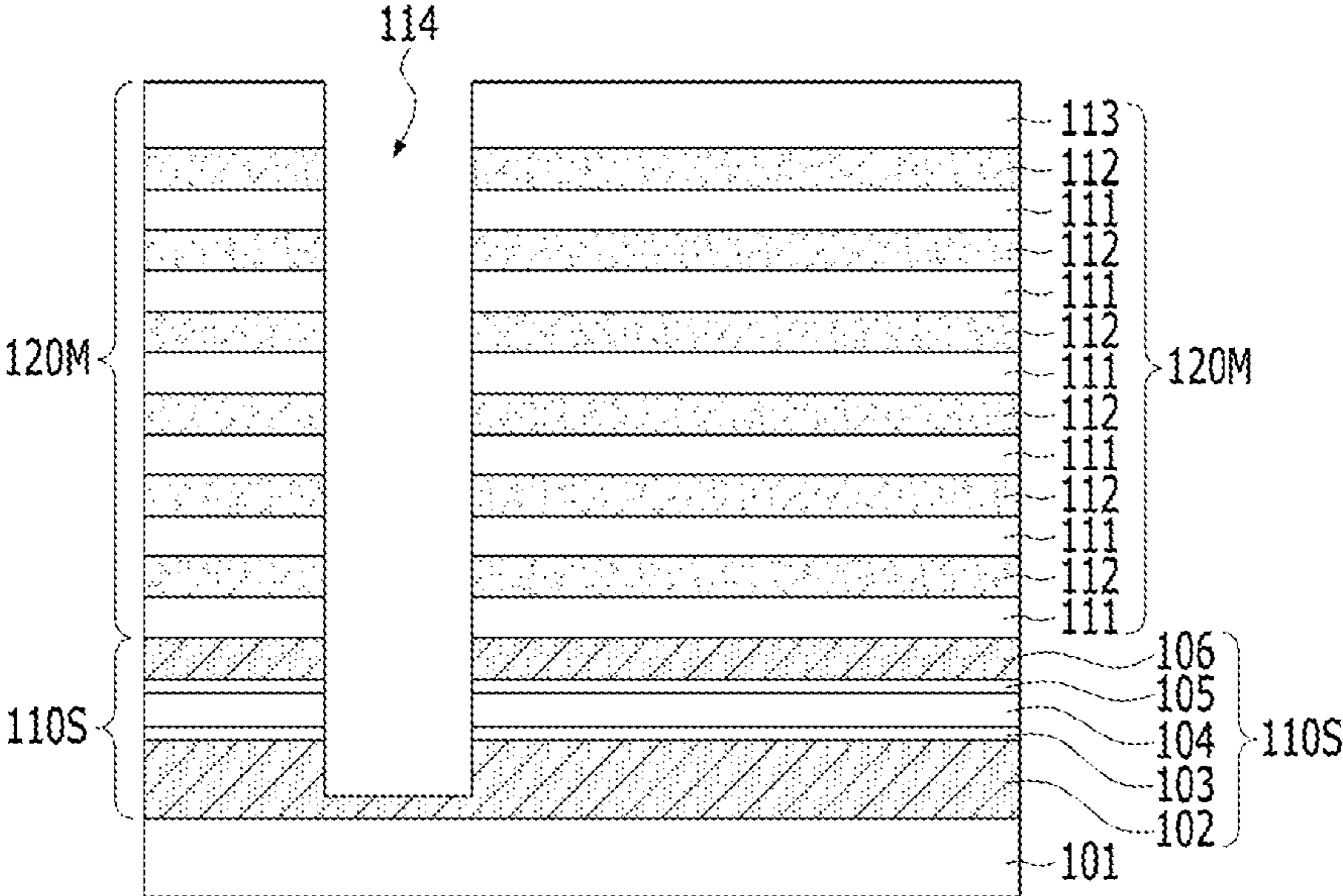


FIG. 4

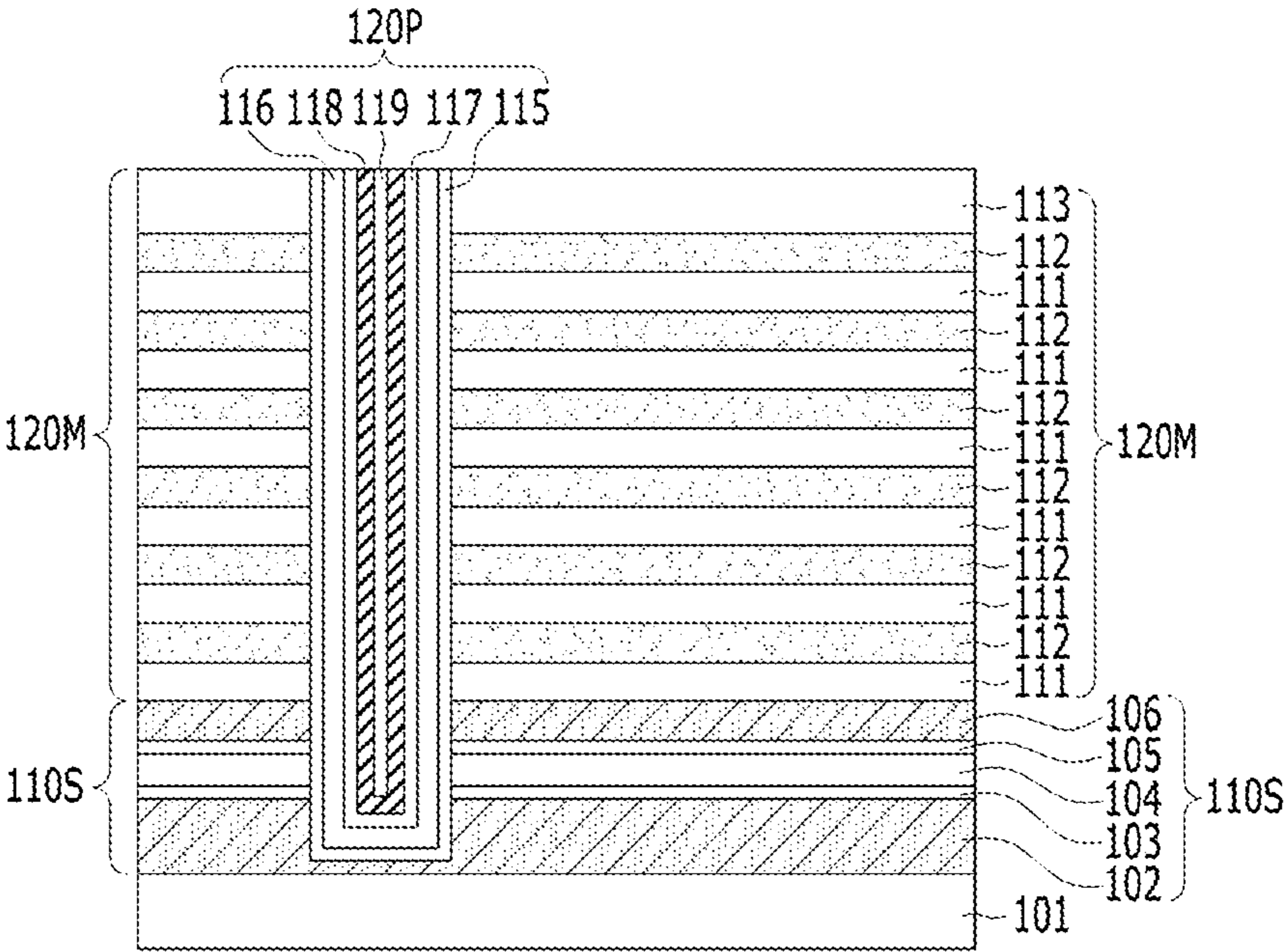




FIG. 7

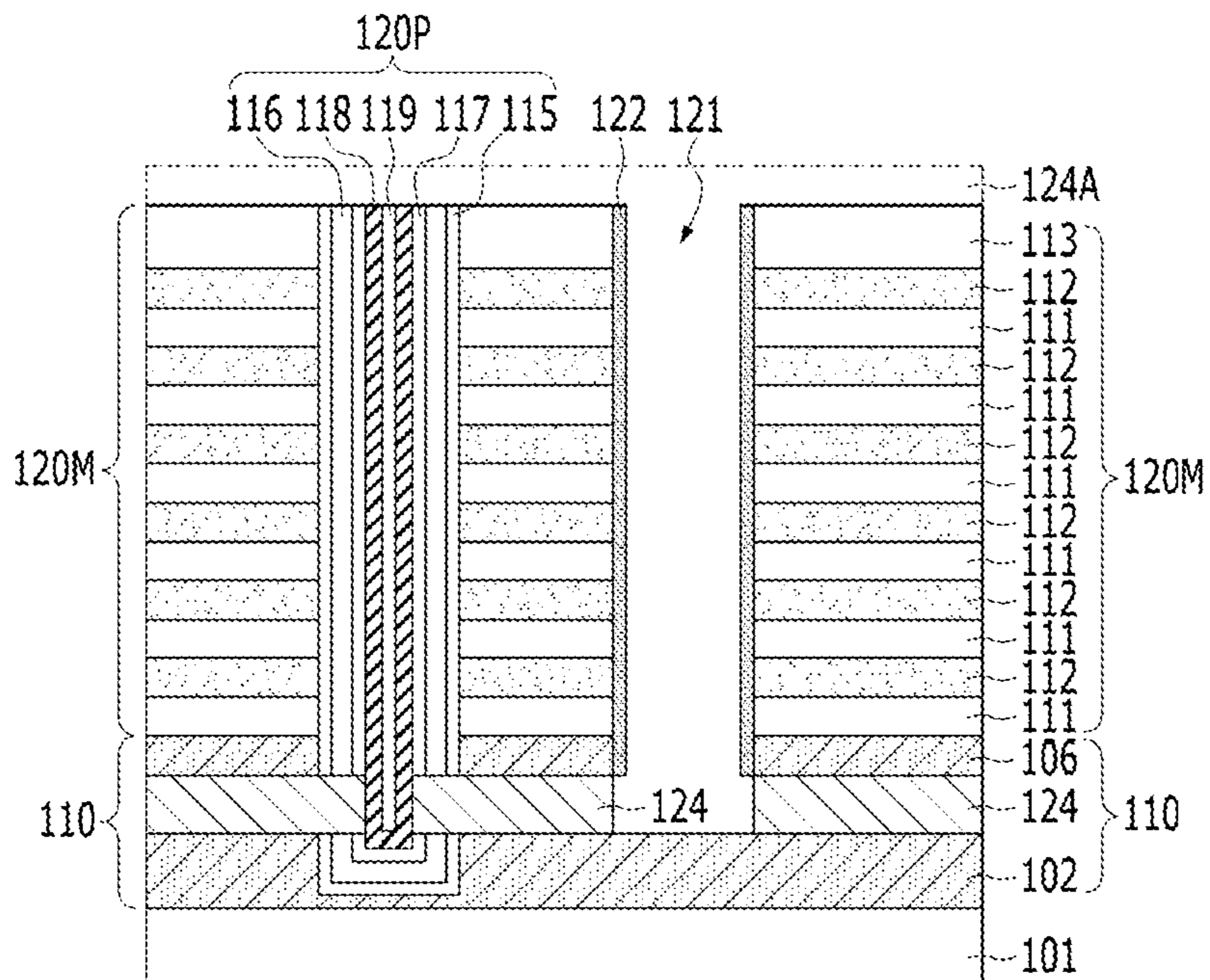


FIG. 8

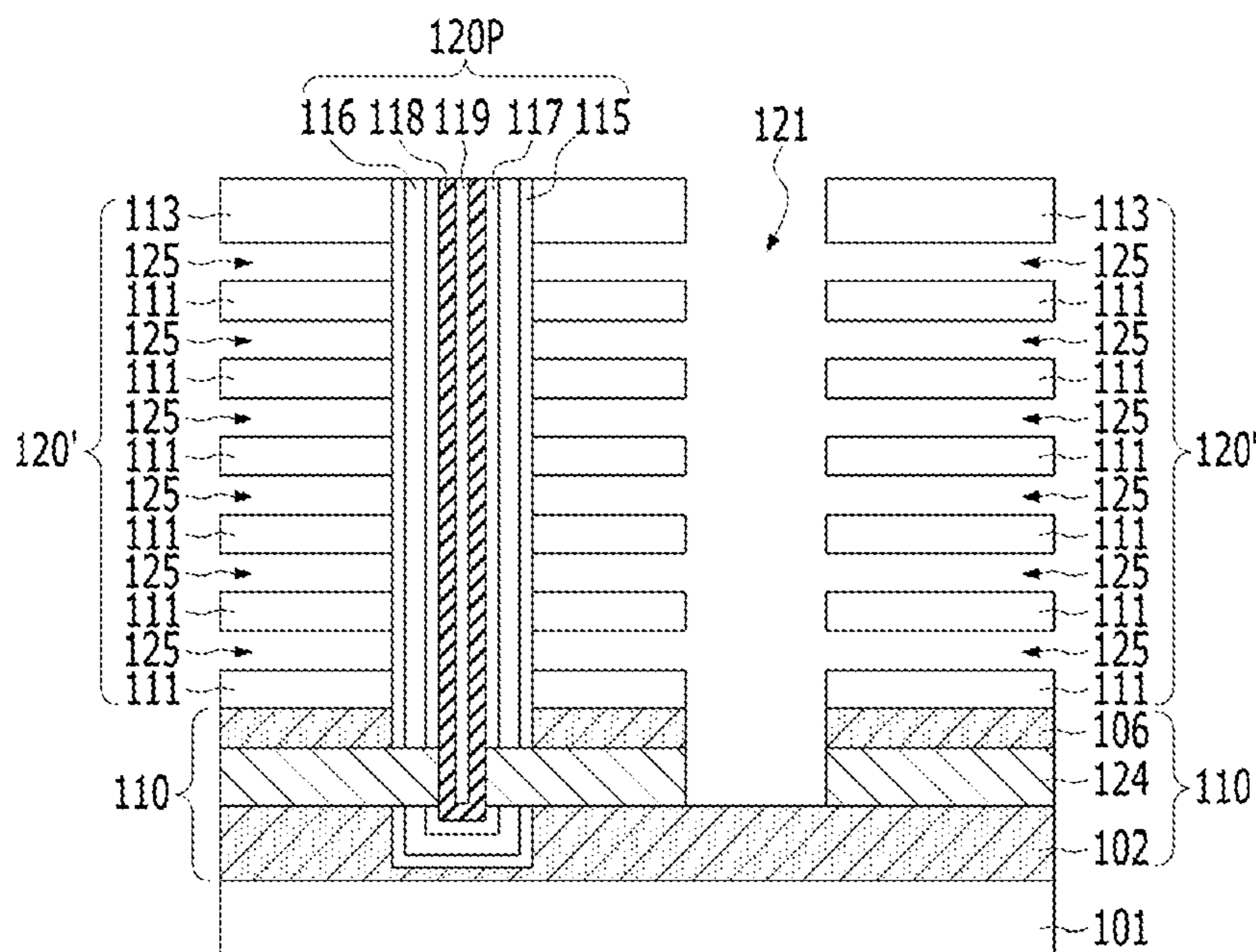


FIG. 9

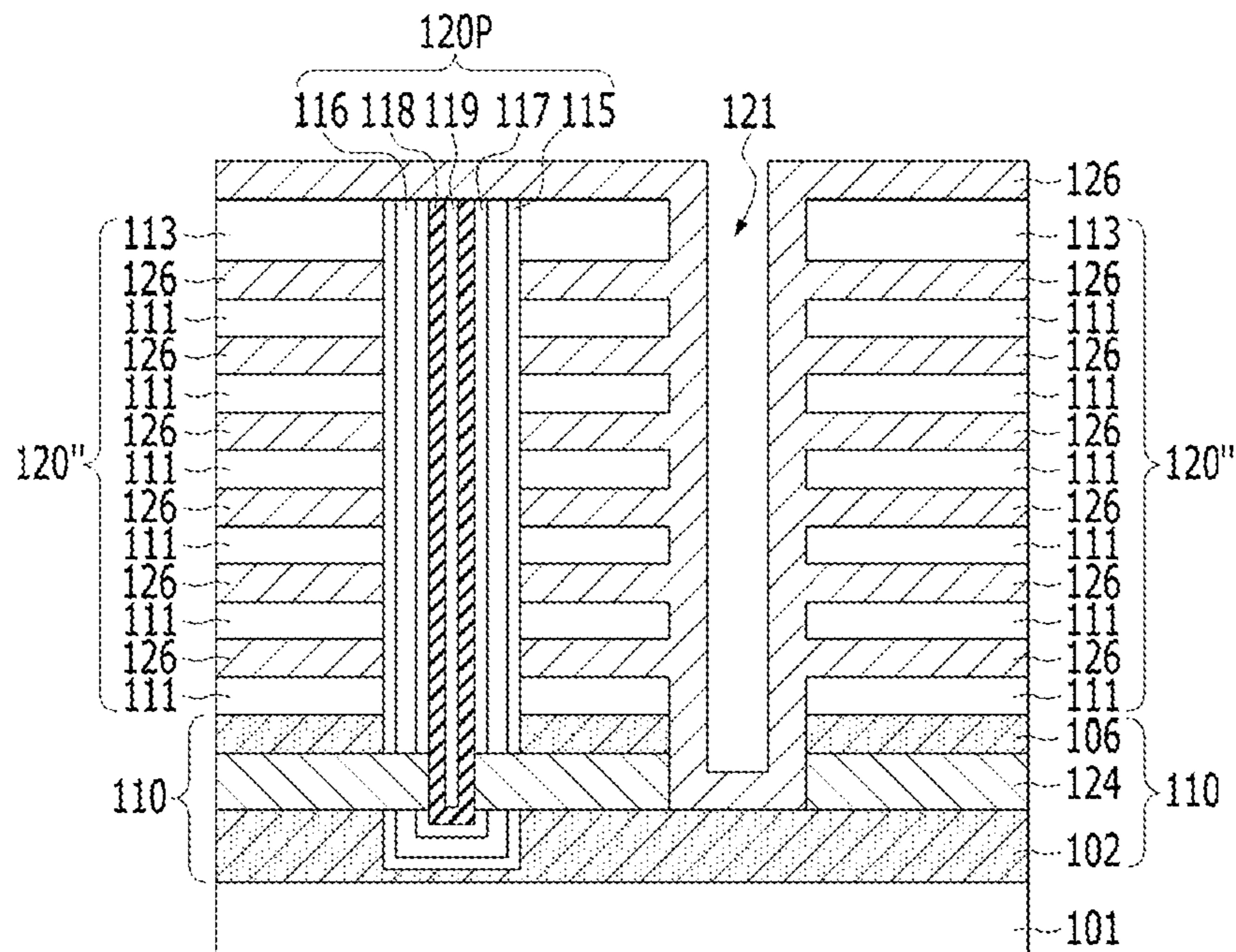


FIG. 10

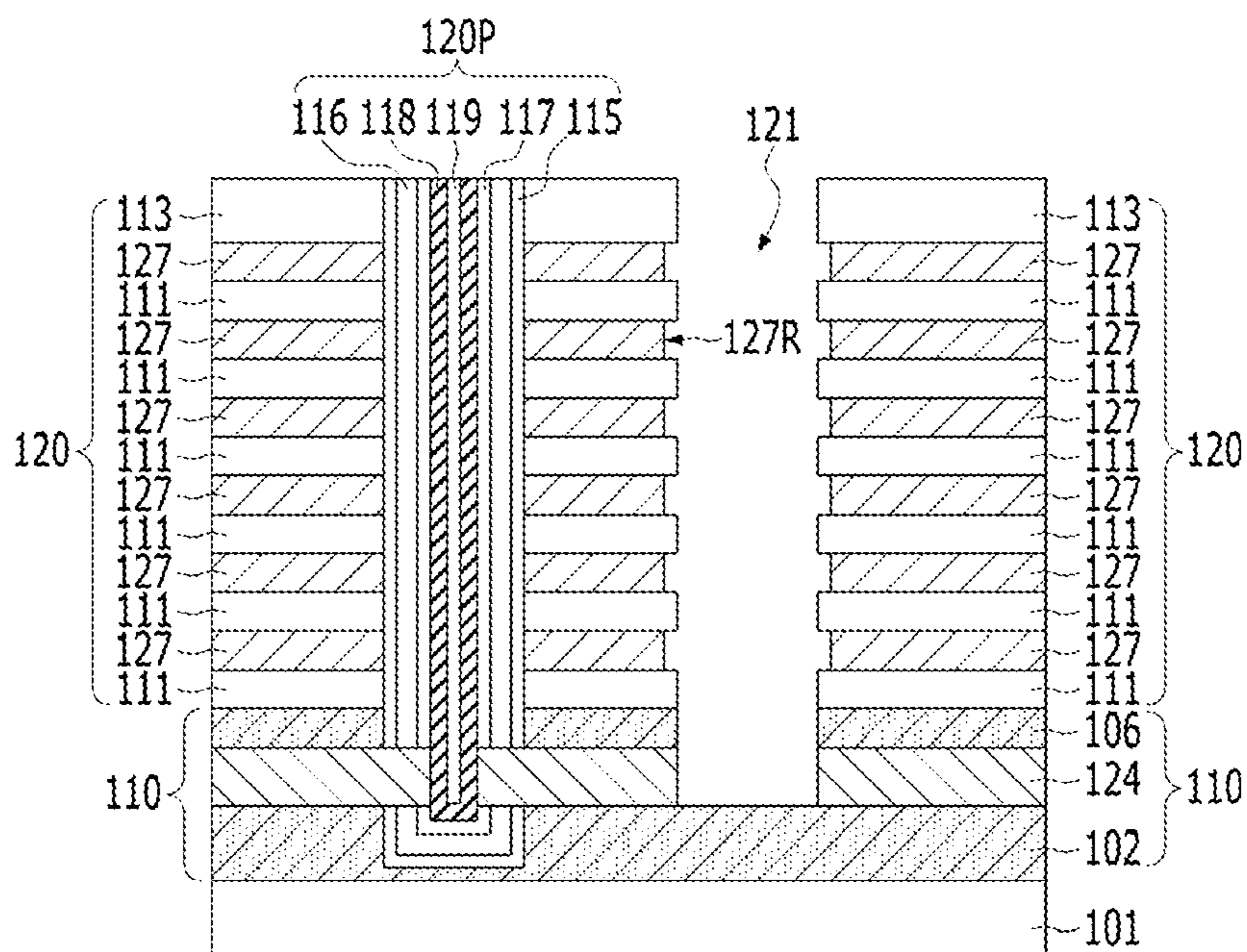


FIG. 11

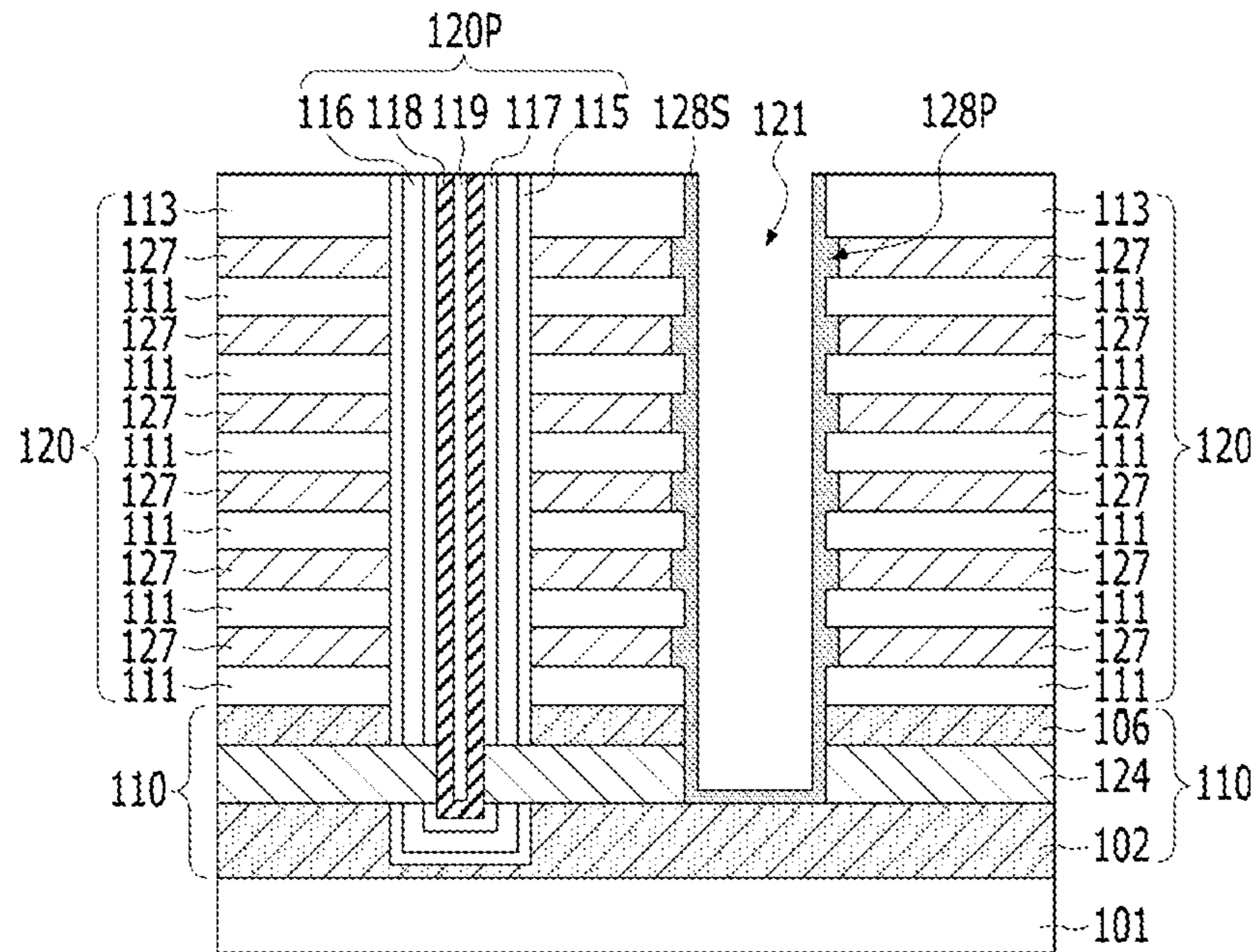


FIG. 12

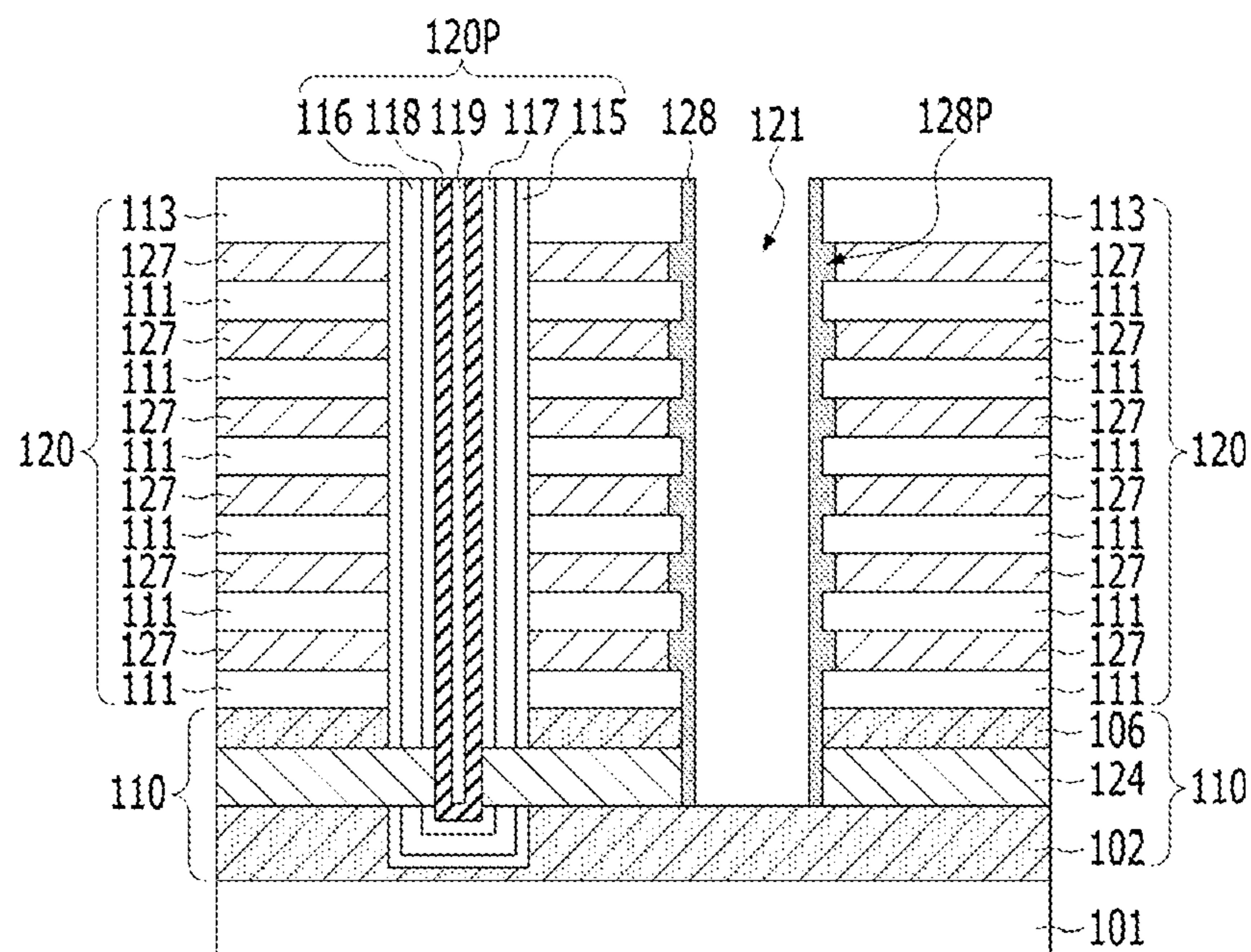




FIG. 13

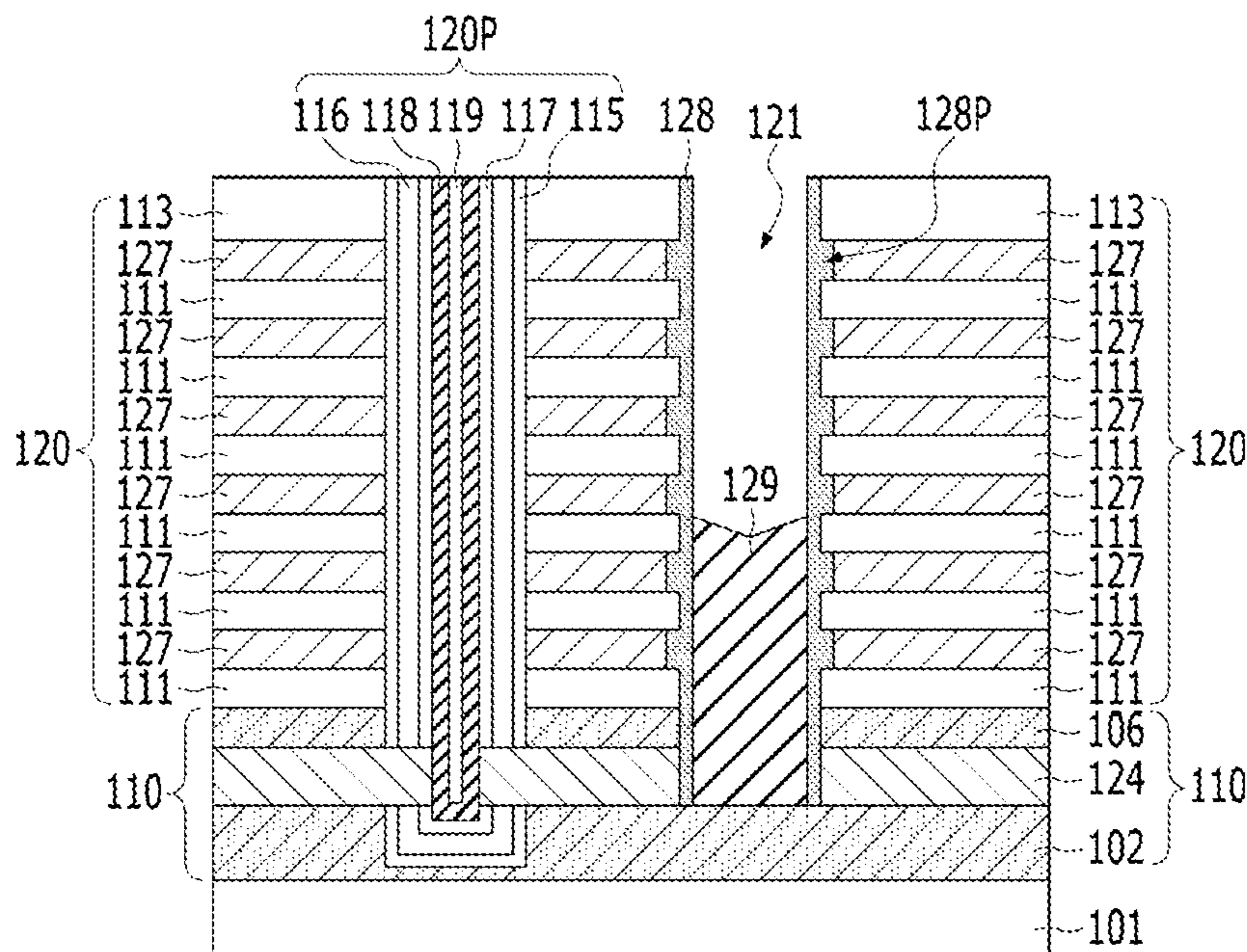


FIG. 14

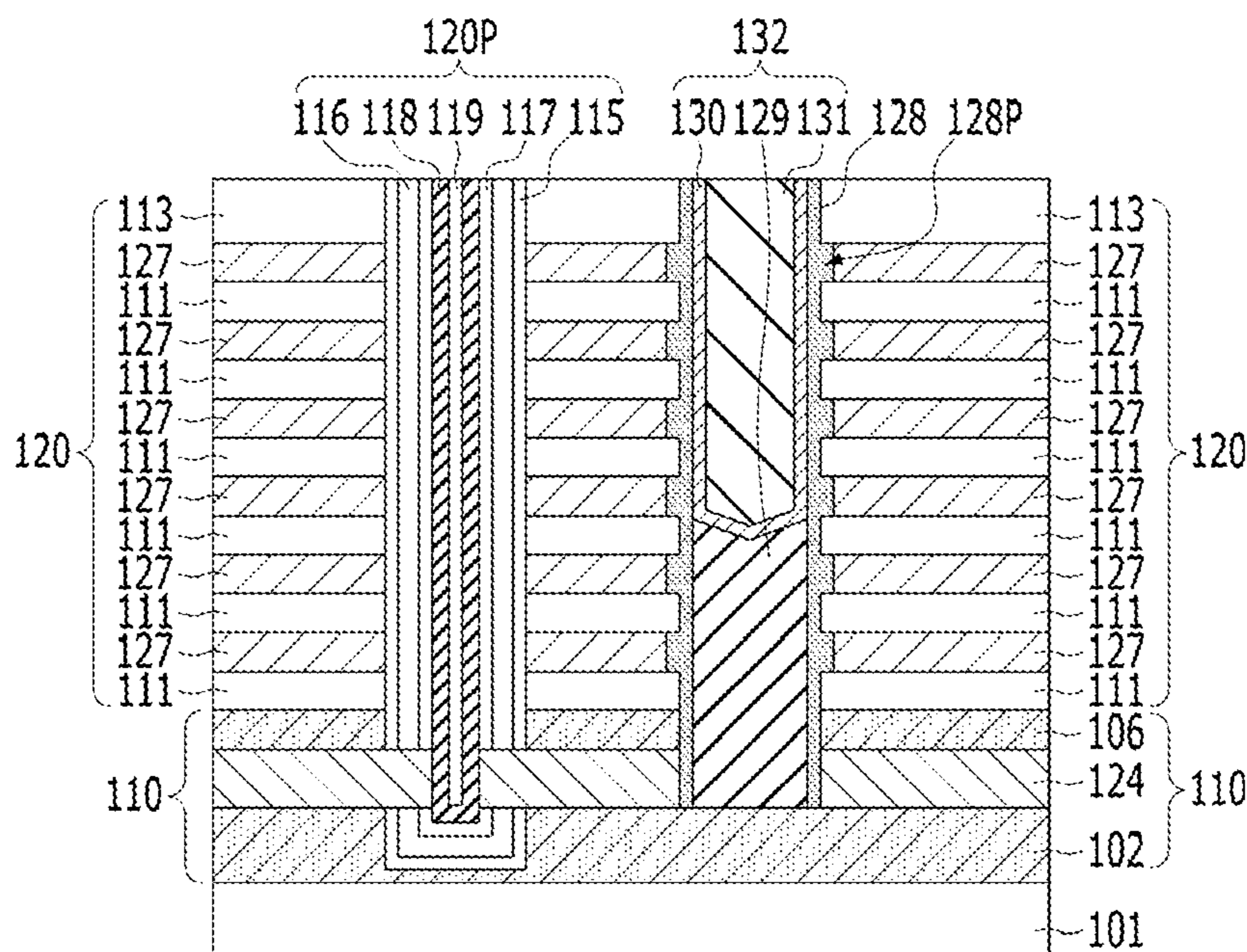


FIG. 15

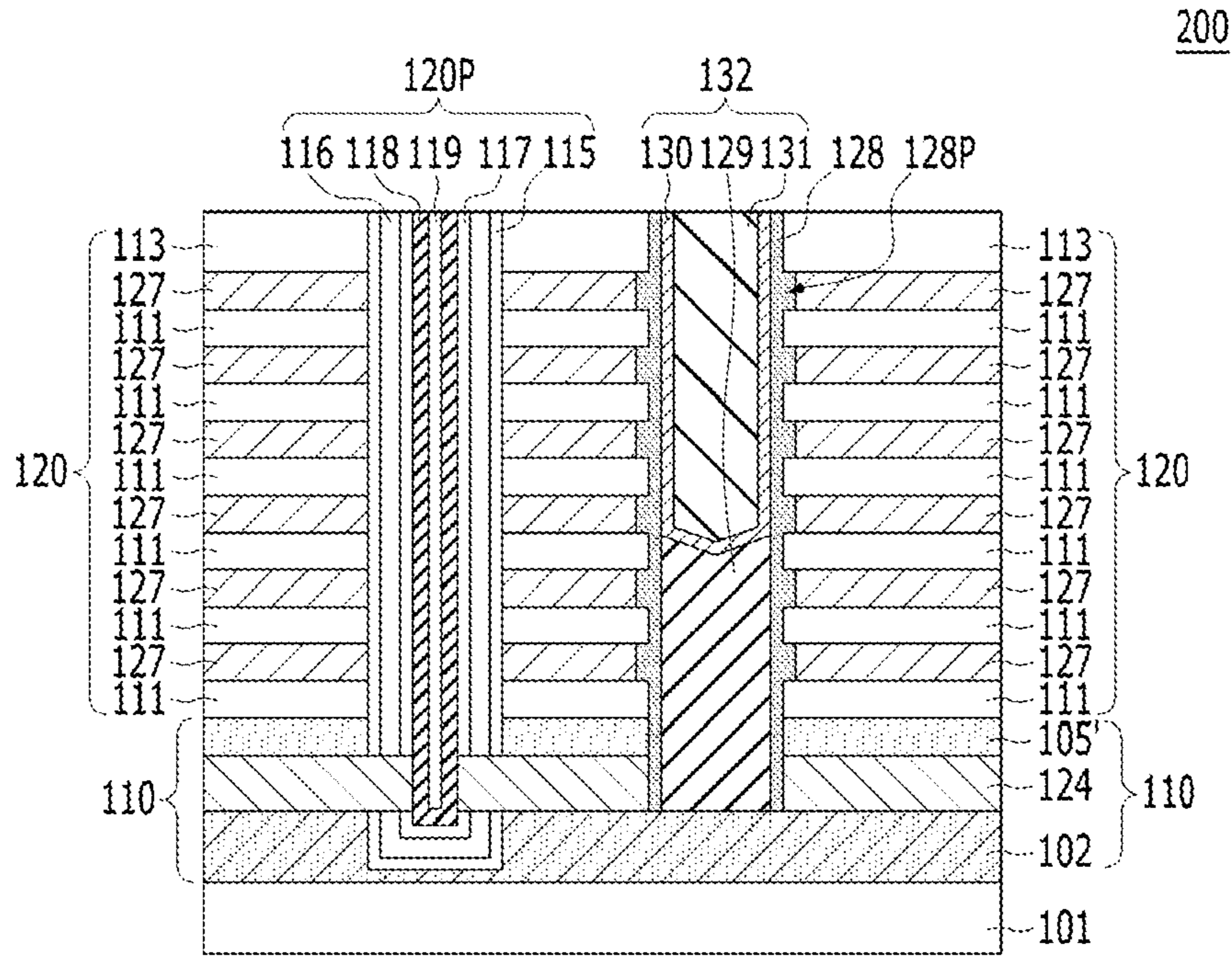


FIG. 16

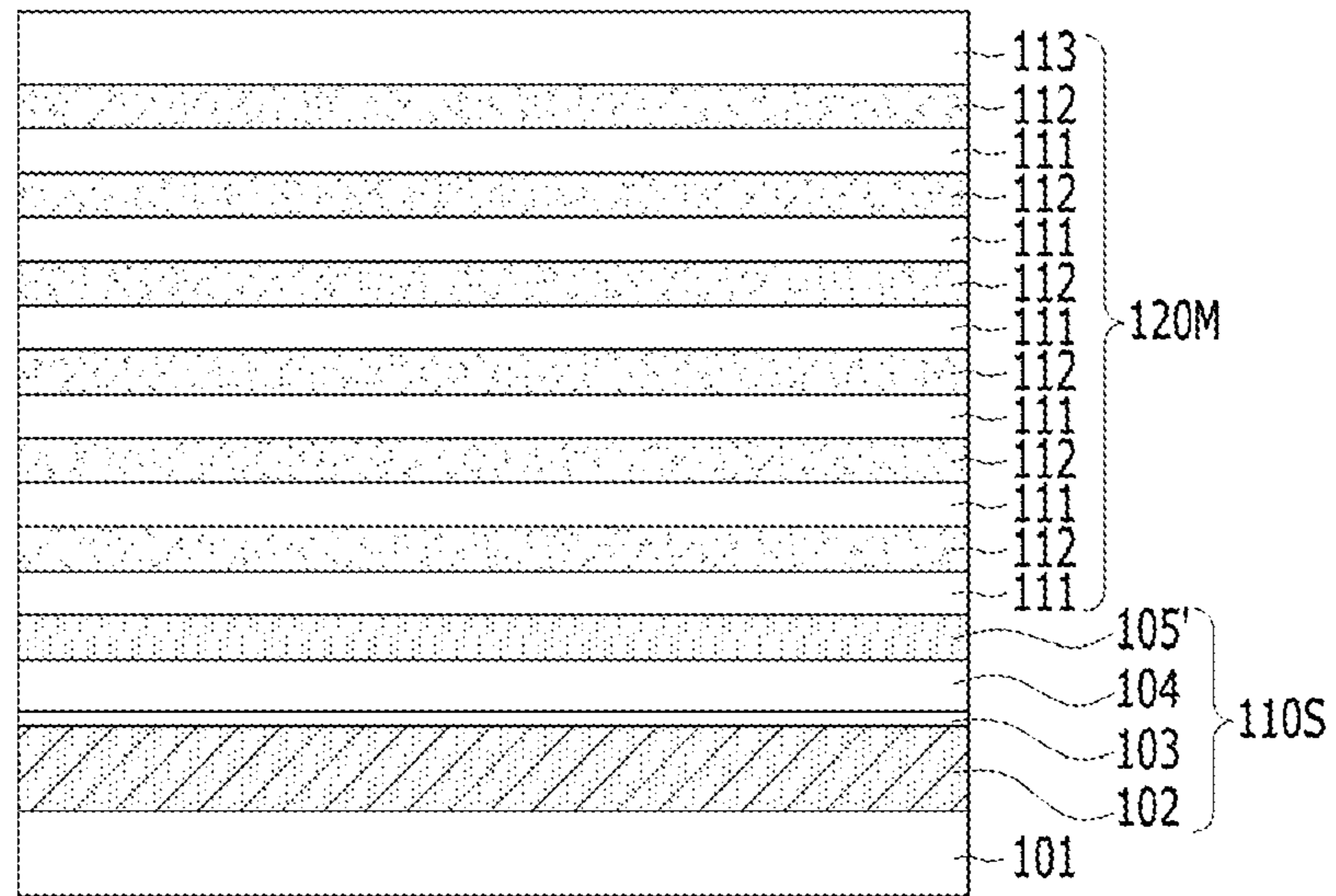


FIG. 17

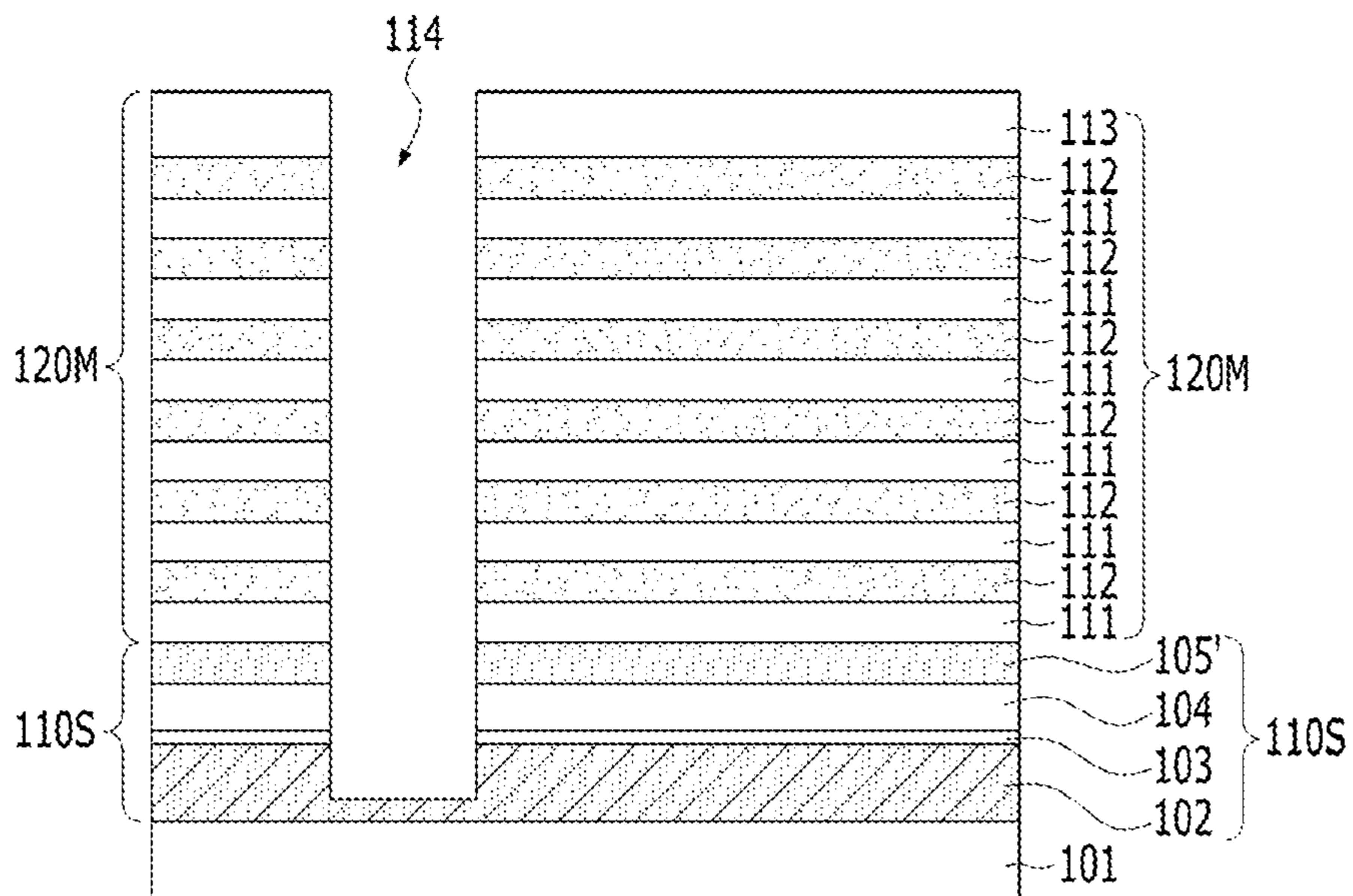


FIG. 18

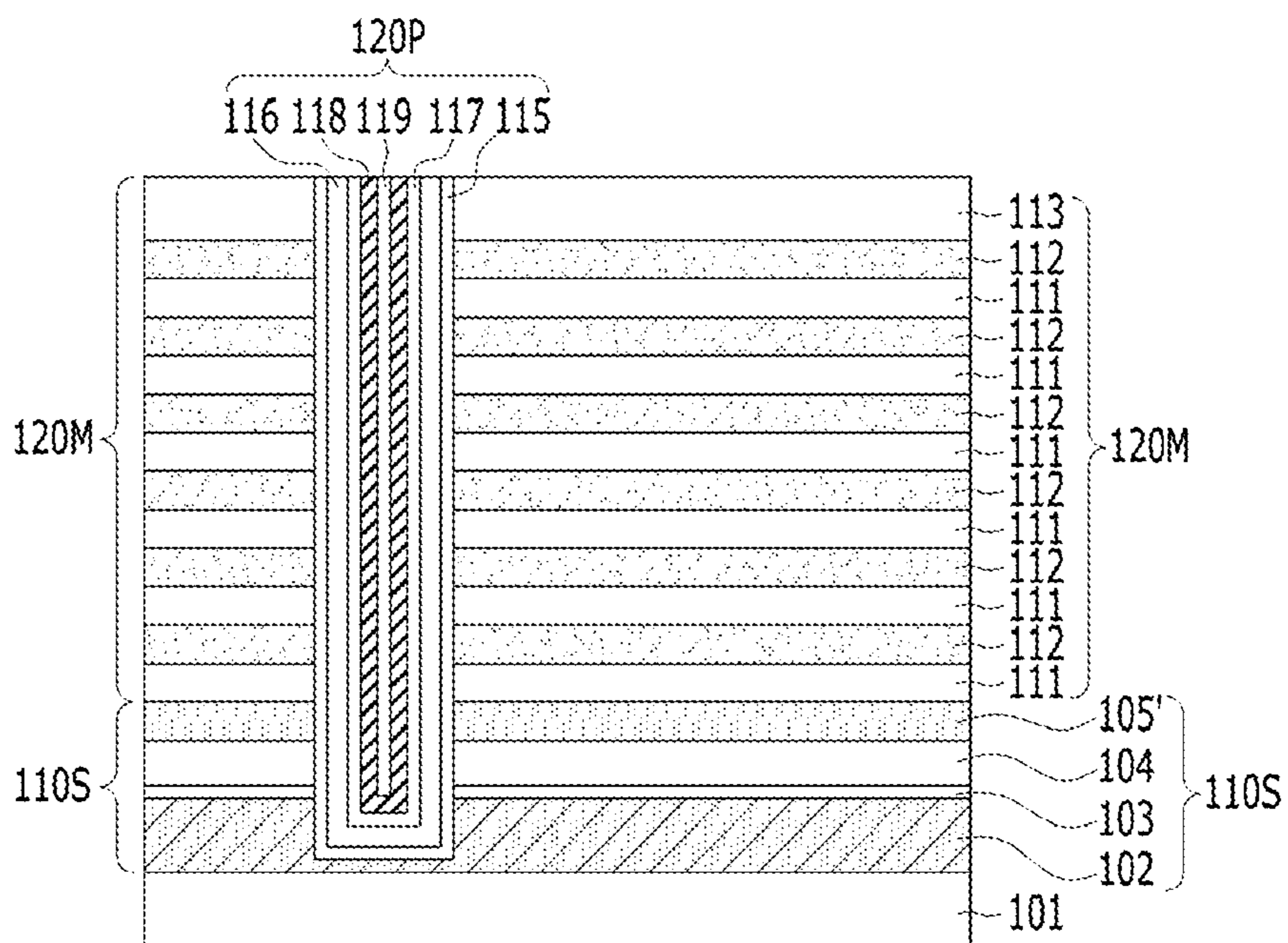


FIG. 19

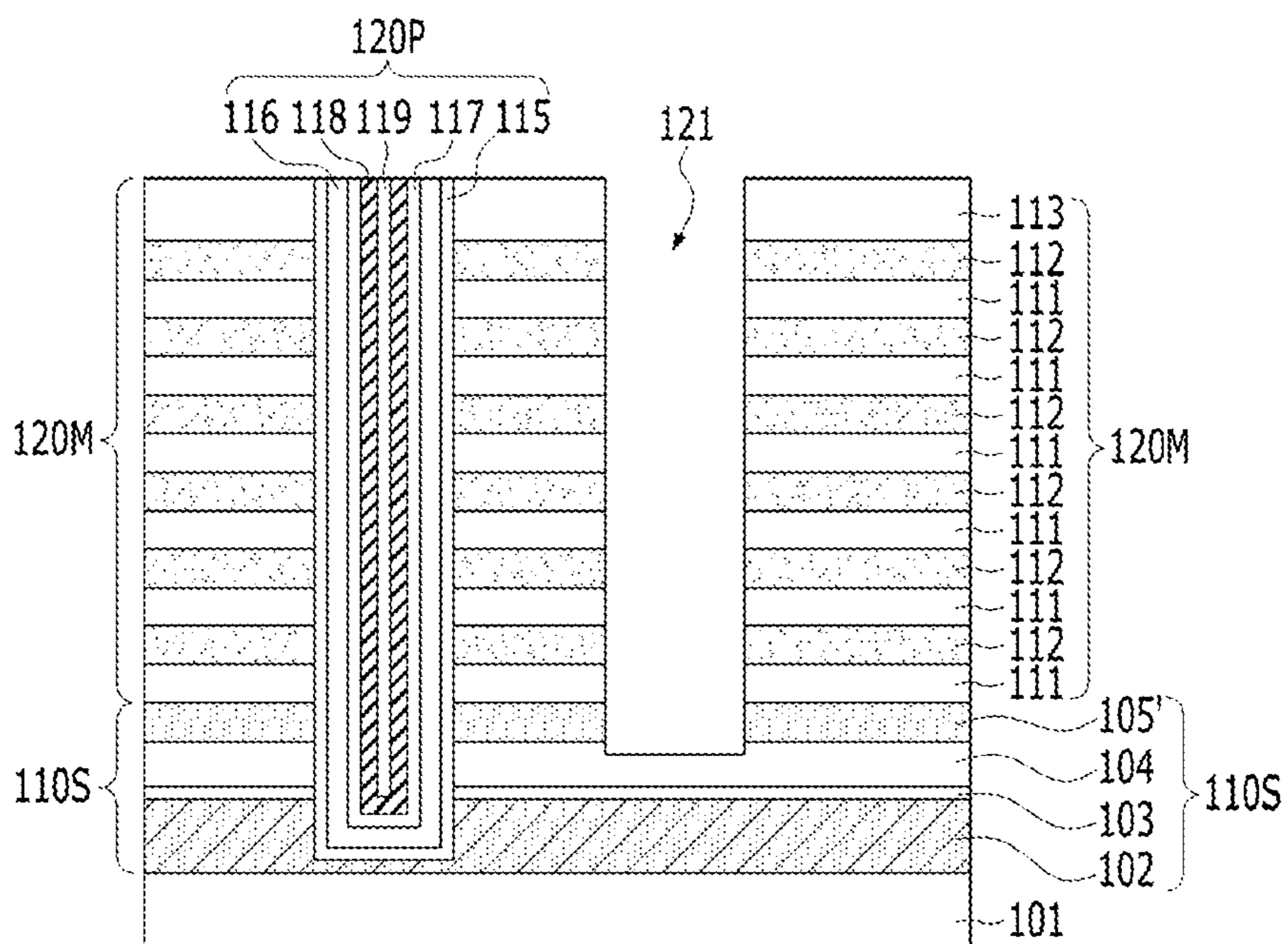


FIG. 20

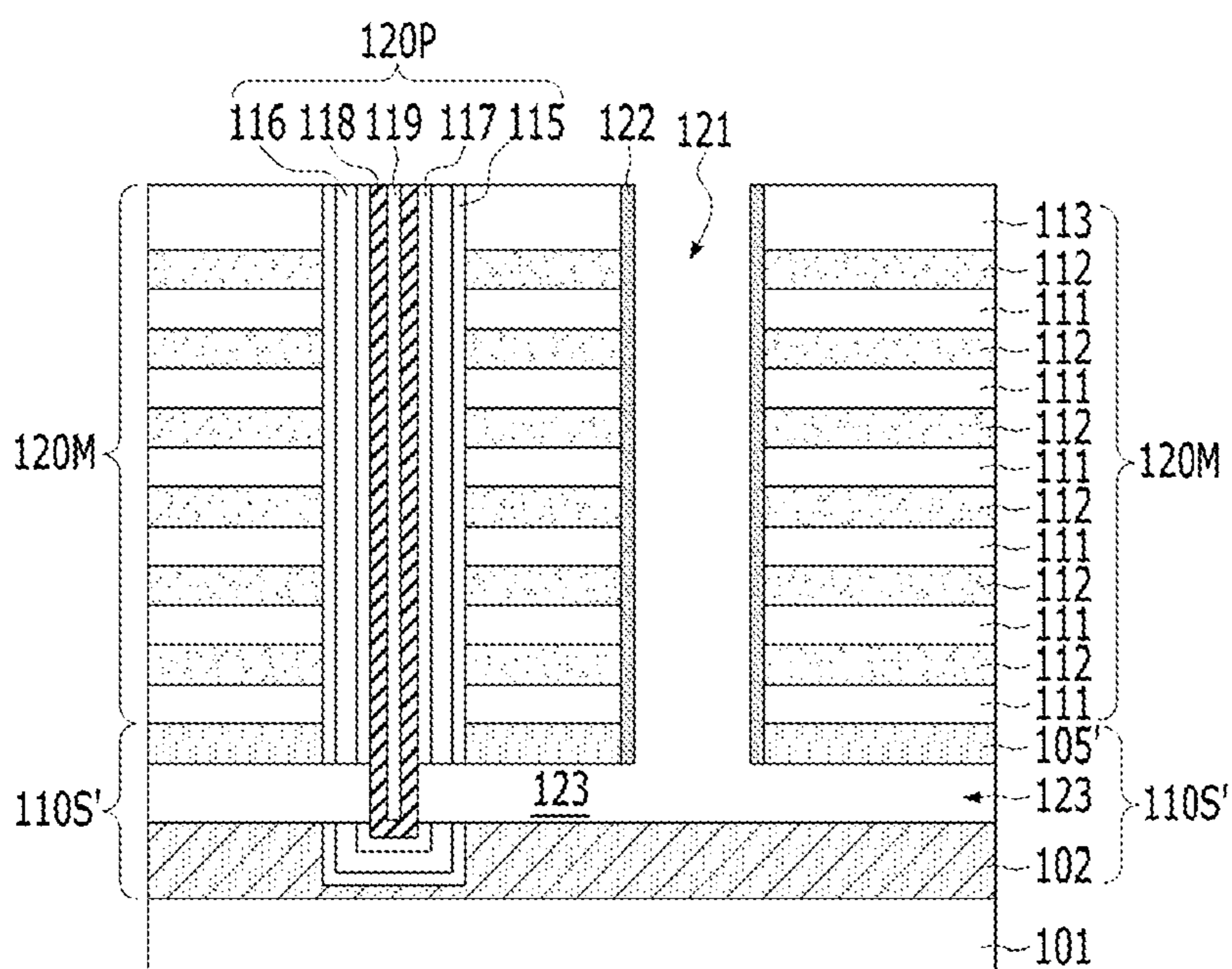


FIG. 21

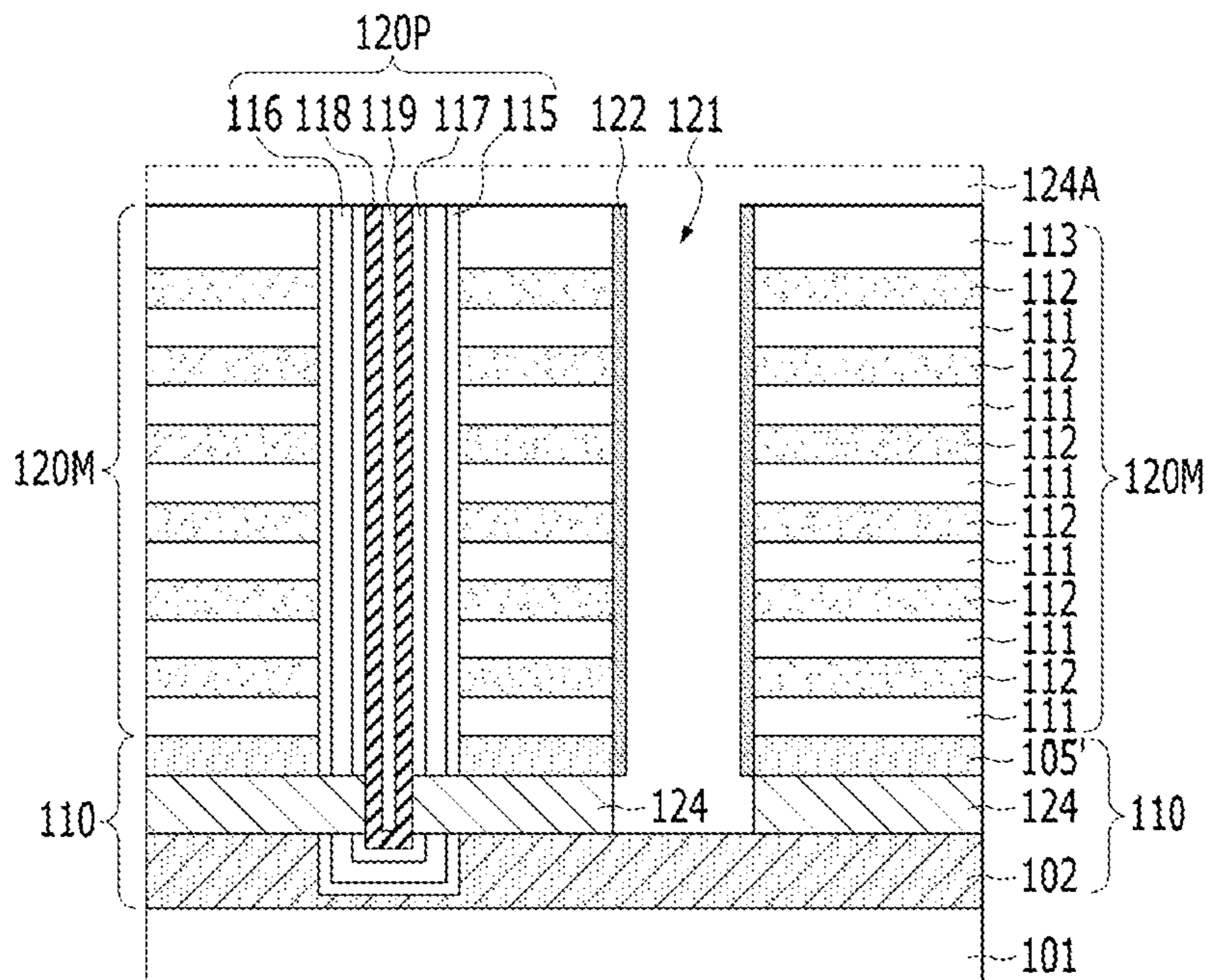


FIG. 22

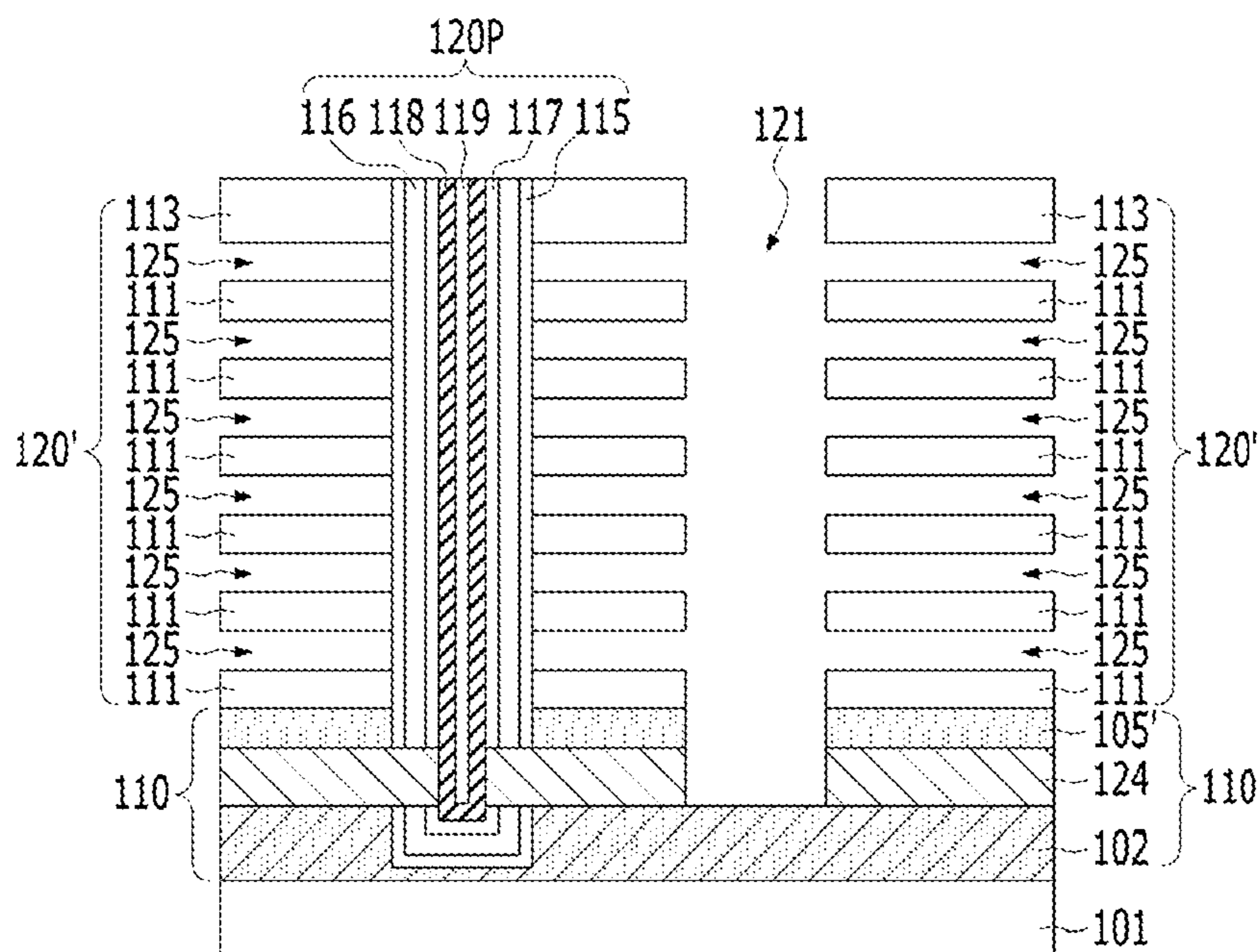


FIG. 23

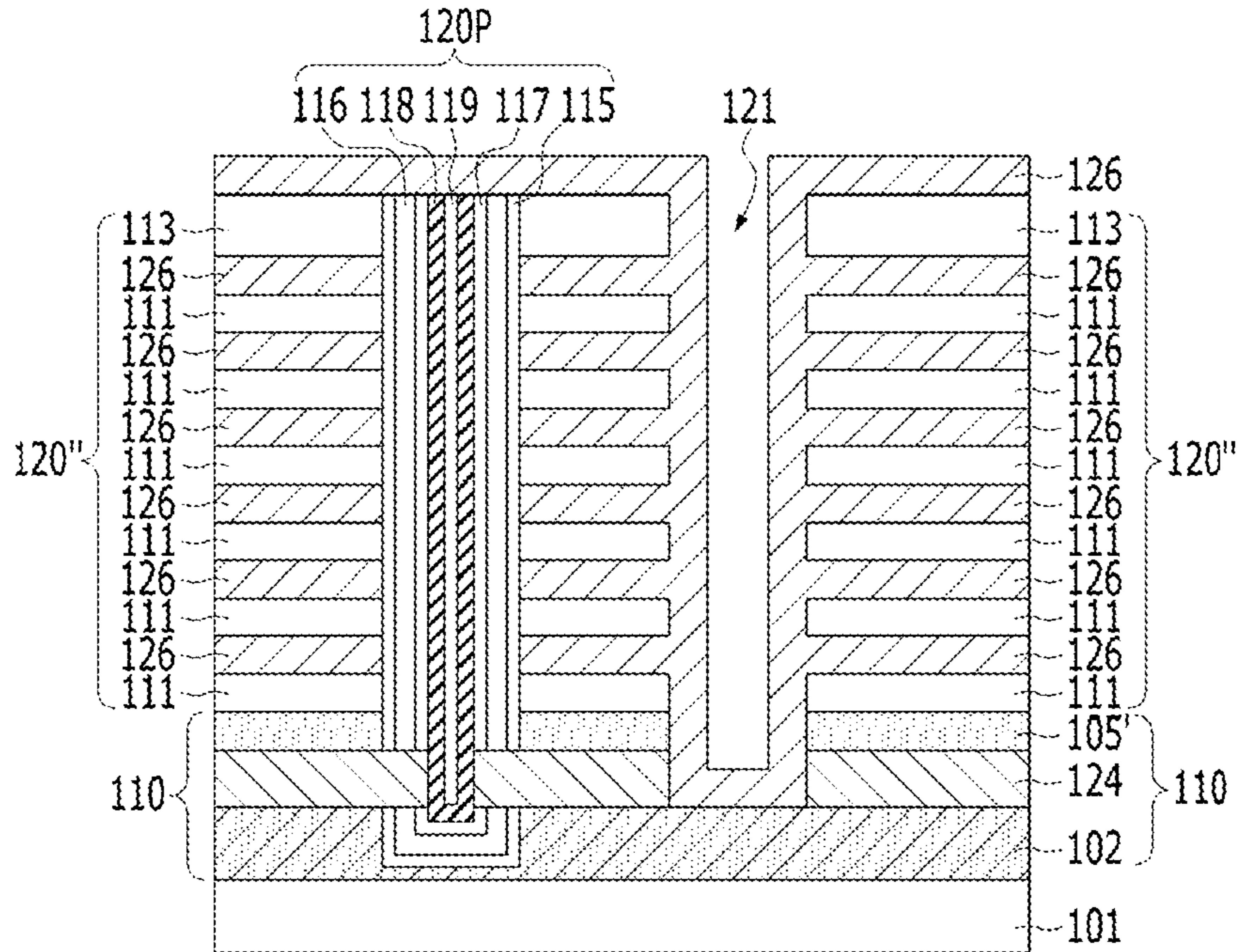


FIG. 24

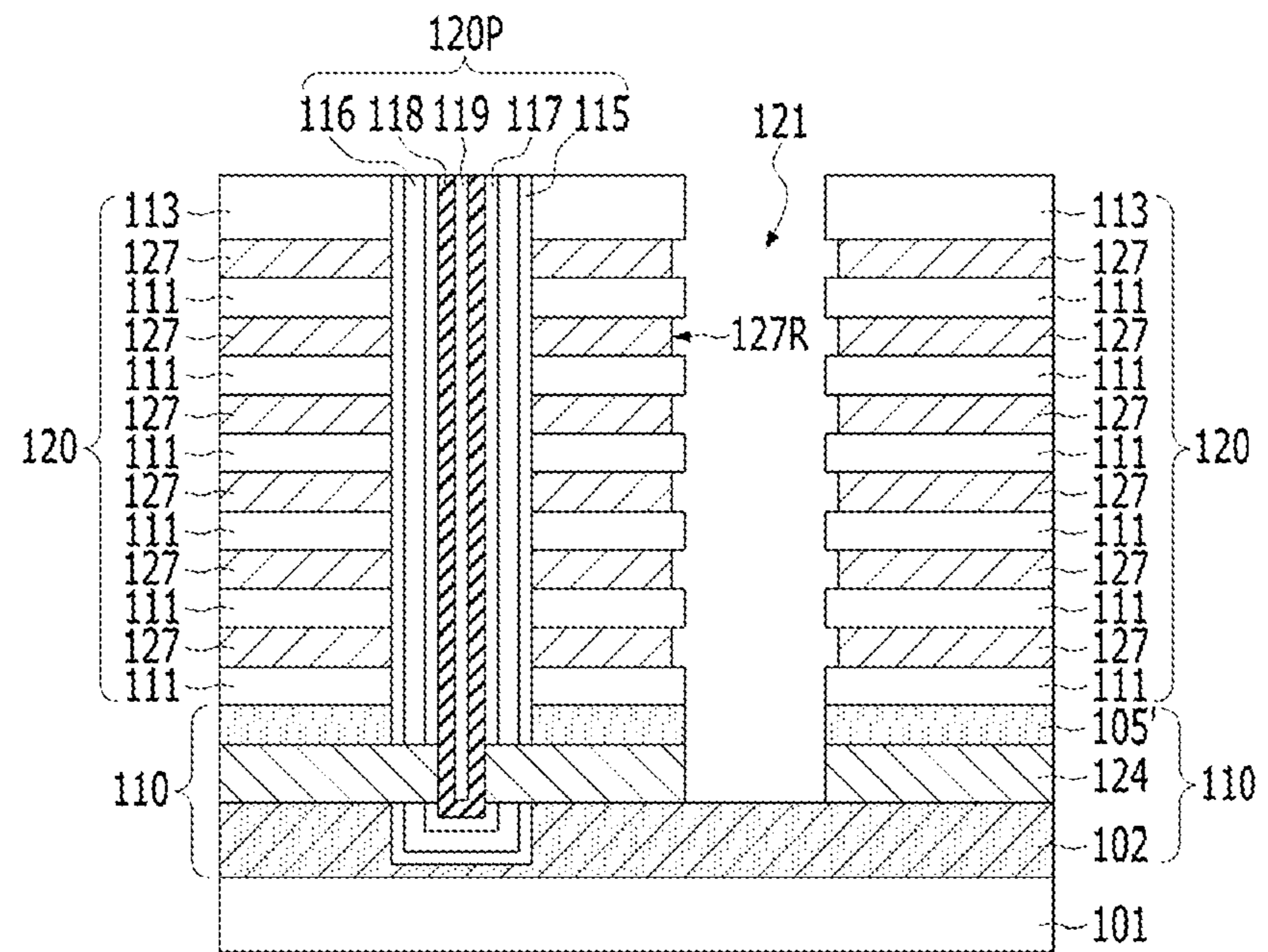


FIG. 25

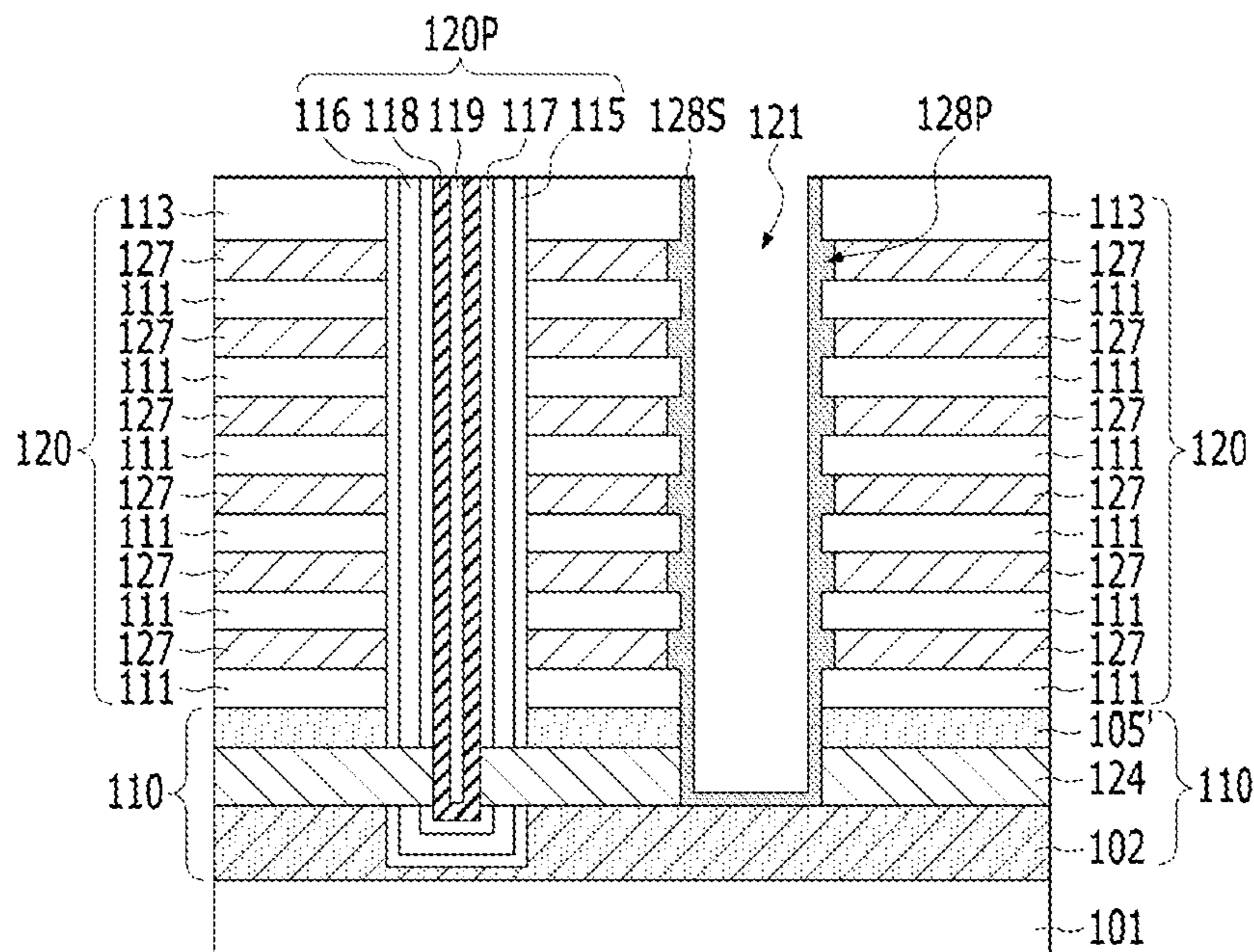


FIG. 26

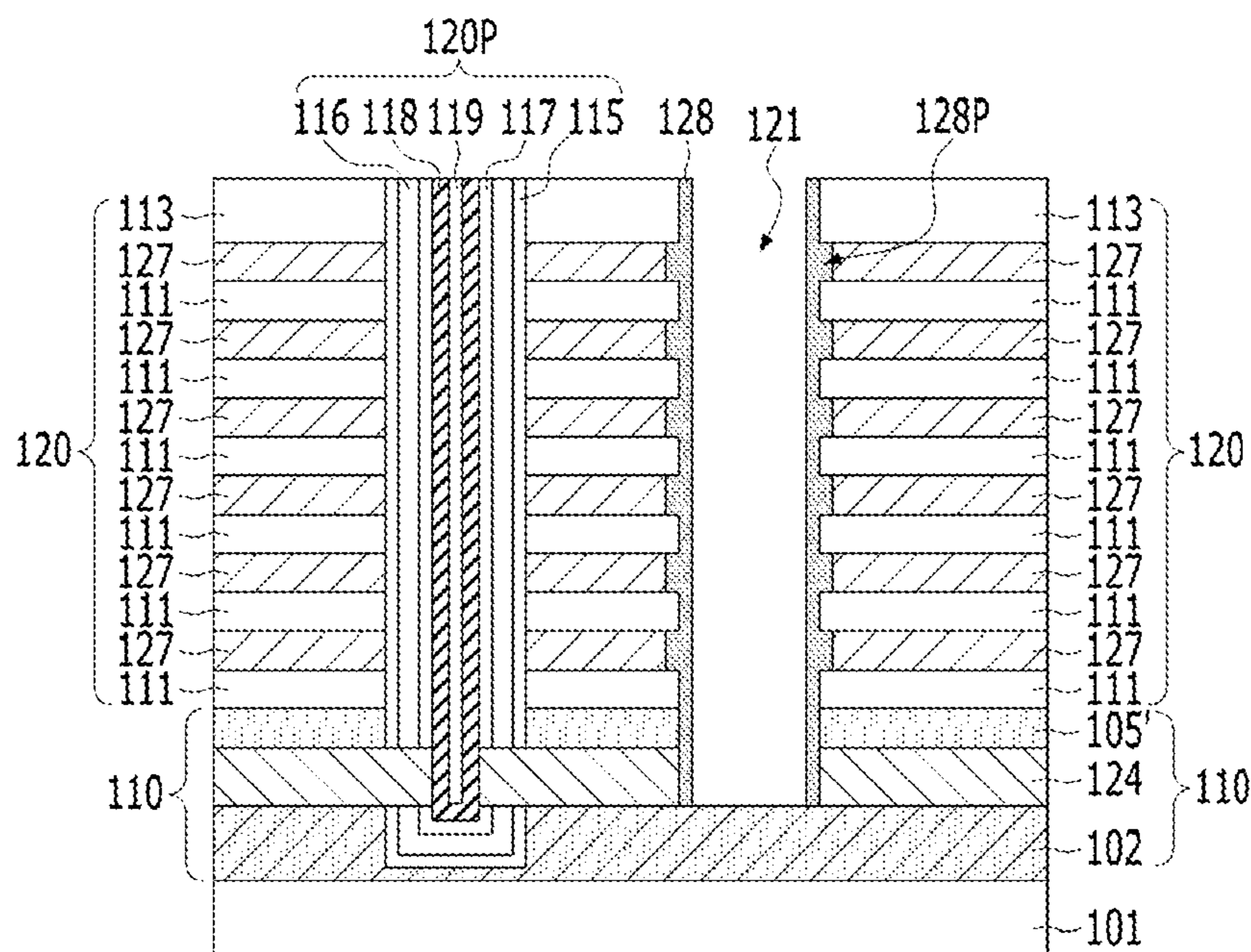


FIG. 27

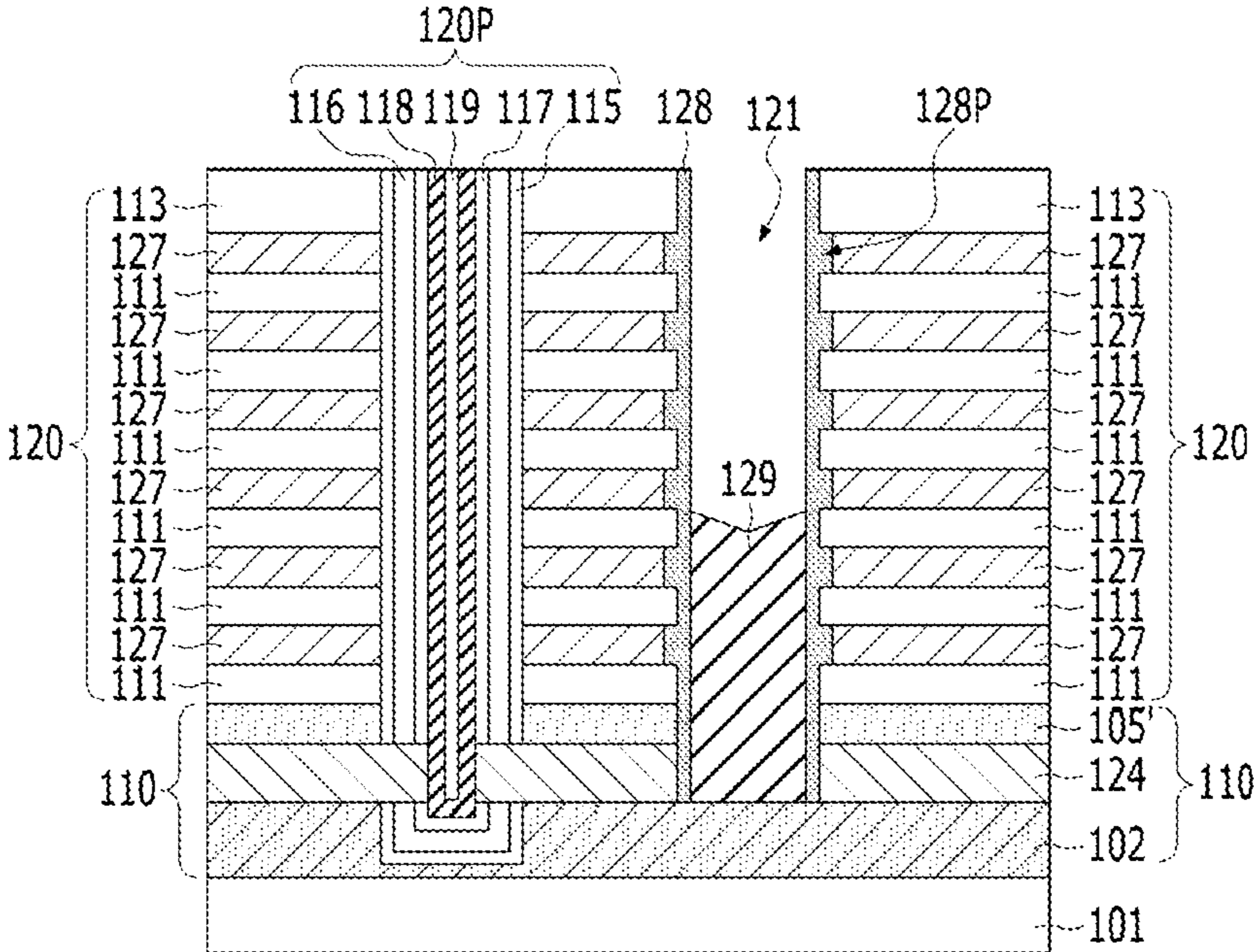
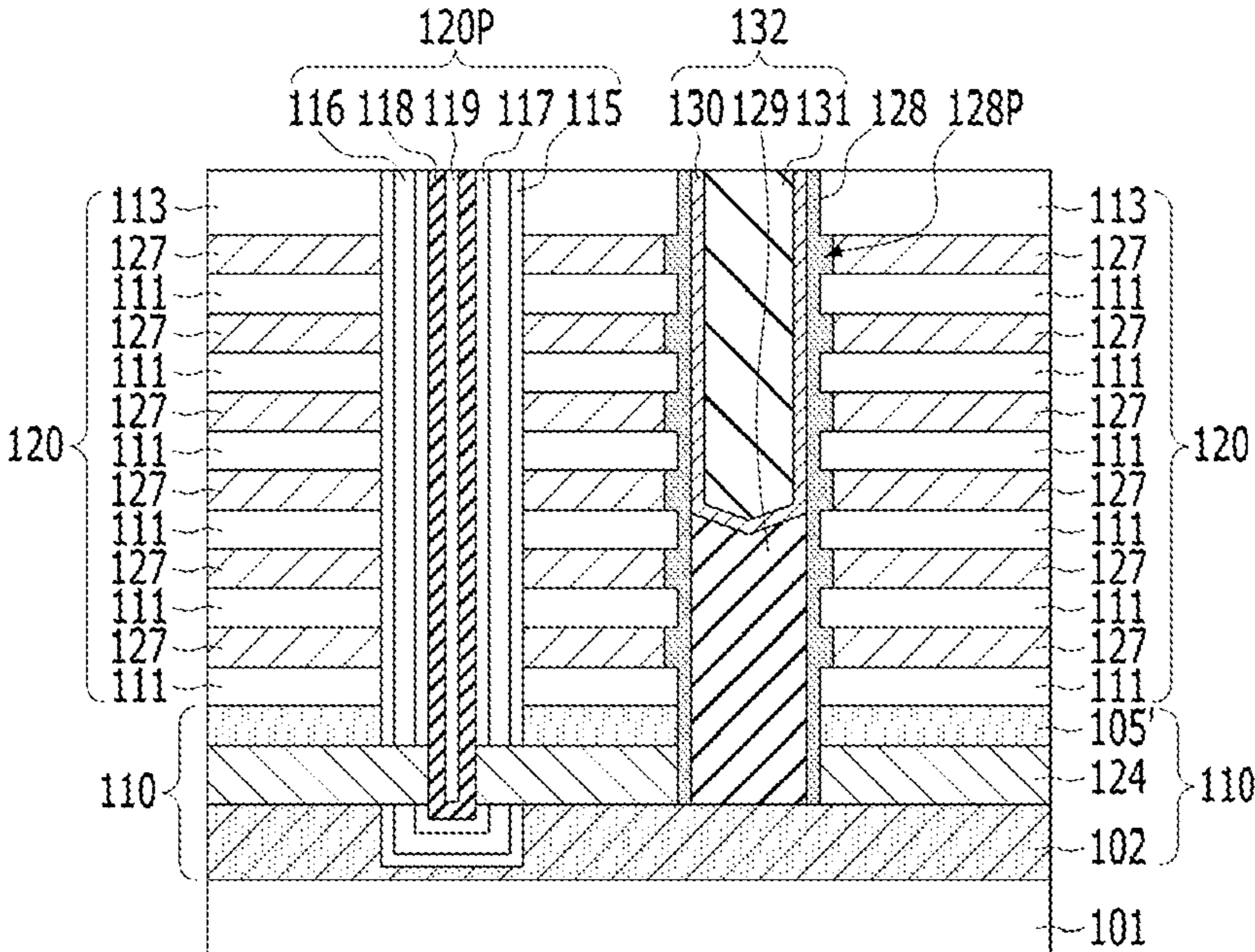


FIG. 28





## VERTICAL SEMICONDUCTOR DEVICE AND METHOD FOR FABRICATING THE SAME

### CROSS-REFERENCE TO RELATED APPLICATION

The present application is the continuation of U.S. application Ser. No. 17/585,133 filed Jan. 26, 2022, which is the continuation of U.S. application Ser. No. 16/842,141 filed Apr. 7, 2020, now U.S. Pat. No. 11,271,008, and claims priority of Korean Patent Application No. 10-2019-0156872, filed on Nov. 29, 2019, which is incorporated herein by reference in its entirety.

### BACKGROUND

#### 1. Field

Embodiments of the present disclosure relate to a semiconductor device, and more particularly, to a method for fabricating a vertical semiconductor device.

#### 2. Description of the Related Art

Fabrication of electronic devices such as semiconductor devices includes a gapfill process for forming a three-dimensional structure or a high aspect ratio structure. The gapfill process to form a high aspect ratio structure is performed, for example, in the fabrication of a vertical semiconductor device.

### SUMMARY

Embodiments of the present disclosure are directed to a vertical semiconductor device with improved reliability, and a method for fabricating the vertical semiconductor device.

In accordance with an embodiment of the present disclosure, a semiconductor device includes: an alternating stack that is disposed over a lower structure and includes gate electrodes and dielectric layers which are stacked alternately; a memory stack structure that includes a channel layer extending to penetrate through the alternating stack, and a memory layer surrounding the channel layer; a source contact layer in contact with a lower outer wall of the vertical channel layer and disposed between the lower structure and the alternating stack; a source contact plug spaced apart from the memory stack structure and extending to penetrate through the alternating stack; and a sealing spacer suitable for sealing the gate electrodes and disposed between the source contact plug and the gate electrodes, the sealing spacer having an etch resistance that is different from an etch resistance of the dielectric layers.

In accordance with another embodiment of the present disclosure, a method for fabricating a semiconductor device includes: forming a source sacrificial layer over a lower structure; forming a multi-layer stack in which dielectric layers and sacrificial layers are alternately stacked over the source sacrificial layer; forming a memory stack structure that includes a channel layer and a memory layer, the memory stack structure extending to penetrate through the multi-layer stack and the source sacrificial layer; forming a vertical contact recess that is spaced apart from the memory stack structure and extends to penetrate through the multi-layer stack and the source sacrificial layer; exposing a lower outer wall of the channel layer by selectively removing the source sacrificial layer and a lower portion of the memory layer of the memory stack structure through the vertical

contact recess; forming a source contact layer that surrounds the lower outer wall of the channel layer; replacing the sacrificial layers of the multi-layer stack with gate electrodes to form an alternating stack; forming a carbon-containing spacer to seal a sidewall of the vertical contact recess over the source contact layer and the gate electrodes; and forming a source contact plug in the vertical contact recess.

In accordance with another embodiment of the present disclosure, a method for fabricating a semiconductor device includes: forming a first multi-layer stack including liner layers and a source sacrificial layer over a lower structure; forming a second multi-layer stack including dielectric layers and sacrificial layers over the first multi-layer stack; forming a vertical contact recess extending through the second multi-layer stack and the source sacrificial layer; replacing the source sacrificial layer with a source contact layer; forming a carbon-containing spacer on sidewall of the vertical contact recess; replacing the sacrificial layers with conductive layers; and forming a source contact plug in the vertical contact recess.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view illustrating a vertical semiconductor device in accordance with an embodiment of the present disclosure.

FIGS. 2 to 14 are cross-sectional views illustrating a method for fabricating a vertical semiconductor device in accordance with an embodiment of the present disclosure.

FIG. 15 is a cross-sectional view illustrating a vertical semiconductor device in accordance with another embodiment of the present disclosure.

FIGS. 16 to 28 are cross-sectional views illustrating a method for fabricating a vertical semiconductor device in accordance with another embodiment of the present disclosure.

### DETAILED DESCRIPTION

Embodiments of the present disclosure will be described below in more detail with reference to the accompanying drawings. Embodiments of the present disclosure may, however, be implemented in different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of various embodiments of the present disclosure to those skilled in the art. Throughout the disclosure, like reference numerals refer to like parts throughout the various figures and embodiments of the present disclosure.

The drawings are not necessarily to scale and in some instances, proportions may have been exaggerated in order to clearly illustrate features of the embodiments. When a first layer is referred to as being “on” a second layer or “on” a substrate, it not only refers to a case where the first layer is formed directly on the second layer or the substrate but also a case where a third layer exists between the first layer and the second layer or the substrate.

FIG. 1 is a cross-sectional view illustrating a vertical semiconductor device 100 in accordance with an embodiment of the present disclosure.

Referring to FIG. 1, the vertical semiconductor device 100 may be positioned over a lower structure 101, and the vertical semiconductor device 100 may include an alternating stack 120 in which dielectric layers 111 and gate electrodes 127 are alternately stacked, a memory stack structure 120P including a channel layer 118 extending to

penetrate the alternating stack **120** and a stack of layers (or a memory layer) **115**, **116**, and **117** surrounding the channel layer **118**, a source contact layer **124** disposed between the lower structure **101** and the alternating stack **120** while contacting an outer wall of a bottom portion of the channel layer **118**, a source contact plug **132** spaced apart from the memory stack structure **120P** and extending through the alternating stack **120**, and a sealing spacer **128** having a different etch resistance from that of the dielectric layers **111** while sealing an outer wall of the source contact plug **132**. The sealing spacer **128** may seal the gate electrodes **127** and be disposed between the source contact plug **132** and the gate electrodes **127**, and may have different etch resistance from the dielectric layers **111**. The outer wall of the source contact plug **132** may be surrounded by the sealing spacer **128**, and the sealing spacer **128** may vertically extend to cover the gate electrodes **127**, the dielectric layers **111**, and the source contact layer **124**.

The lower structure **101** may include a material suitable for semiconductor processing. The lower structure **101** may include a substrate, and the substrate may include a semiconductor substrate. For example, the lower structure **101** may be a silicon substrate, a monocrystalline silicon substrate, a polysilicon substrate, an amorphous silicon substrate, a silicon germanium substrate, a monocrystalline silicon germanium substrate, a polycrystalline silicon germanium substrate, a carbon-doped silicon substrate, a combination thereof, or a multi-layer thereof. The lower structure **101** may include other semiconductor materials, such as germanium. The lower structure **101** may include a III/V-group semiconductor substrate, such as a compound semiconductor substrate, e.g., GaAs. The lower structure **101** may include a Silicon-On-Insulator (SOI) substrate. Although not shown, according to another embodiment of the present disclosure, the lower structure **101** may include a substrate, at least one control circuit formed over the substrate, and a multi-layer metal line.

A multi-layer stack structure may be formed over the lower structure **101**. The multi-layer stack structure may include a source-level stack **110** and an alternating stack **120** over the source-level stack **110**. The source-level stack **110** may have a height lower than a height of the alternating stack **120**.

The source-level stack **110** may include a lower source layer **102**, a source contact layer **124**, and an upper source layer **106**. The source contact layer **124** may be formed over the lower source layer **102**, and the upper source layer **106** may be formed over the source contact layer **124**. The source contact layer **124** may be disposed between the lower source layer **102** and the upper source layer **106**. The lower source layer **102**, the upper source layer **106**, and the source contact layer **124** may include a semiconductor material. The lower source layer **102**, the upper source layer **106**, and the source contact layer **124** may include polysilicon. The source contact layer **124** may include polysilicon doped with phosphorus (P). The source contact layer **124** may include polysilicon containing carbon. The source contact layer **124** may include a stack of phosphorus-doped polysilicon (SiP) and carbon-doped polysilicon (SiC). The lower source layer **102** and the upper source layer **106** may include undoped polysilicon or doped polysilicon.

The alternating stack **120** may be referred to as a memory cell stack or a memory cell string. The alternating stack **120** may have a structure in which a plurality of dielectric layers **111** and a plurality of gate electrodes **127** are alternately stacked. The top dielectric layer **113** among the dielectric layers **111** may be thicker than the dielectric layers **111** at

lower levels than the top dielectric layer **113**. The dielectric layers **111** may include silicon oxide. The gate electrodes **127** may include a low-resistance material. The gate electrodes **127** may include a metal-based material. The gate electrodes **127** may include metal, metal silicide, metal nitride, or a combination thereof. For example, the metal may include nickel, cobalt, platinum, titanium, tantalum, or tungsten. The metal silicide may include nickel silicide, cobalt silicide, platinum silicide, titanium silicide, tantalum silicide, or tungsten silicide. The gate electrodes **127** may include a stack of titanium nitride and tungsten. The ends of the gate electrodes **127** may have a shape that is horizontally recessed from the ends of the dielectric layers **111**.

The memory stack structure **120P** may extend vertically to penetrate through the alternating stack **120**. The memory stack structure **120P** may have a pillar shape. The memory stack structure **120P** may include a blocking layer **115**, a charge trapping layer **116**, a tunnel dielectric layer **117**, a channel layer **118**, and a core dielectric layer **119**. The memory stack structure **120P** may include an ONOP structure. The ONOP structure may include a stack of oxide, nitride, oxide, and polysilicon layers. The blocking layer **115** and the tunnel dielectric layer **117** may include an oxide, and the charge trapping layer **116** may include a nitride, and the channel layer **118** may include polysilicon. According to an embodiment of the present disclosure, the blocking layer **115** may include a high dielectric material, and the high dielectric material may include aluminum oxide or hafnium oxide. The channel layer **118** may have a cylindrical shape having an inner space. The tunnel dielectric layer **117** may be formed on the outer wall of the channel layer **118**, and the charge trapping layer **116** may be formed on the outer wall of the tunnel dielectric layer **117**. The blocking layer **115** may be formed on the outer wall of the charge trapping layer **116**. The inner space of the channel layer **118** may be substantially completely filled with the core dielectric layer **119**. The core dielectric layer **119** may include silicon oxide or silicon nitride. The stack of the blocking layer **115**, the charge trapping layer **116**, and the tunnel dielectric layer **117** may be referred to as a memory layer **115/116/117**, which may be of an annular shape surrounding the outer wall of the channel layer **118**.

The source contact layer **124** may selectively horizontally penetrate through a bottom portion of the memory layer **115/116/117** of the memory stack structure **120P** to contact the lower outer wall of the channel layer **118**. The source contact layer **124** may have a shape surrounding the lower outer wall of the channel layer **118**.

The source contact plug **132** may include a stack of the silicon-containing material (or the silicon-containing material pattern) **129** and the metal-containing material (or the metal-containing material pattern) **131**, and may further include a barrier material (or a barrier material layer) **130** between the silicon-containing material **129** and the metal-containing material **131**. The silicon-containing material **129** may include polysilicon, and the metal-containing material **131** may include tungsten. The barrier material **130** may include titanium nitride. According to another embodiment of the present disclosure, the source contact plug **132** may be formed of tungsten alone. The lower portion of the source contact plug **132** may be coupled to the lower source layer **102** of the source-level stack **110**.

The sealing spacer **128** may be formed between the source contact plug **132** and the gate electrodes **127**. The sealing spacer **128** may extend to be formed between the dielectric layers **111** and **113** and the source contact plug **132**. For example, the sealing spacer **128** may extend along the

vertical direction in which the gate electrodes **127** and the dielectric layers **111** and **113** of the alternating stack **120** are stacked, such that the sealing spacer **128** may be disposed between the source contact plug **132** and the dielectric layers **111** and **113**. The sealing spacer **128** may be continuous in the stacking direction of the alternating stack **120**. The sealing spacer **128** may include one or more protrusions **128P**, and the protrusions **128P** may be coupled to the ends (e.g., ends **127R** in FIG. **10**) of the gate electrodes **127**, respectively. The protrusions **128P** of the sealing spacer **128** may extend in the horizontal direction that is perpendicular to the stacking direction of the alternating stack **120**. The protrusions **128P** of the sealing spacer **128** may seal the recessed ends of the gate electrodes **127**. The sealing spacer **128** may seal the sides of the dielectric layers **111** and **113**. The sealing spacer **128** may seal the sides of the source contact layer **124**. The sealing spacer **128** may seal the side of the upper source layer **106** and may not seal a portion of the surface of the lower source layer **102**. The sealing spacer **128** may substantially fully surround the outer wall of the source contact plug **132**.

The sealing spacer **128** may include a silicon oxide-based material. The sealing spacer **128** may include a low dielectric material. The low dielectric material may have a lower dielectric constant than silicon nitride. The sealing spacer **128** may have a dielectric constant lower than approximately 7. The sealing spacer **128** may be thinner than the dielectric layers **111** and **113** and the gate electrodes **127**. In the embodiment shown in FIG. **1**, the sealing spacer **128** may have a thickness in the horizontal direction smaller than a thickness of each of the dielectric layers **111** and **113** and the gate electrodes **127** in the vertical direction. For example, a thickness of the protrusion **128P** of the sealing spacer **128** in the horizontal direction may be smaller than a thickness of each of the dielectric layers **111** and **113** and the gate electrodes **127** in the vertical direction. The sealing spacer **128** may be a layer of a material that is different from those of the dielectric layers **111** and **113**. The sealing spacer **128** may be a layer of a material that is different from those of the gate electrodes **127**. The sealing spacer **128** may include a material having a high wet-etch resistance. The wet-etch resistance of the sealing spacer **128** may be obtained from carbon. The sealing spacer **128** may include a carbon-containing material, and the dielectric layers **111** and **113** may be a carbon-free material. The dielectric layers **111** and **113** may be formed of carbon-free silicon oxide, and the sealing spacer **128** may be formed of carbon-containing silicon oxide. For example, the dielectric layers **111** and **113** may be formed of  $\text{SiO}_2$ , and the sealing spacer **128** may be formed of  $\text{SiCO}$ .  $\text{SiCO}$  may be more etch resistant than  $\text{SiO}_2$ . The carbon content of  $\text{SiCO}$  may be less than the content of silicon and the content of oxygen. For example,  $\text{SiCO}$  may have a composition ratio of silicon (Si) 34 at %, oxygen 40 at %, and carbon 17 at %.  $\text{SiCO}$  may have a lower dielectric constant than silicon nitride ( $\text{Si}_3\text{N}_4$ ).

The sealing spacer **128** may be formed to have a thickness of approximately 50 Å to 100 Å. For example, a protrusion **128P** of the sealing spacer **128** may have a thickness in a range from 50 Å to 100 Å in the horizontal direction with respect to the orientation of FIG. **1**. The high wet-etch resistance of  $\text{SiCO}$  may reduce the thickness of the sealing spacer **128**. Specifically, the high wet-etch resistance of  $\text{SiCO}$  may prevent the sealing spacer **128** from being significantly etched when one or more cleaning processes are performed. Thus, even when the sealing spacer **128** is formed to have a relatively small thickness and one or more cleaning process are performed on the sealing spacer **128**,

the thickness of the sealing spacer **128** may remain sufficiently thick to substantially prevent Grown Bad Blocks (GBB) defects. As a result, the size of the source contact plug **132** for separating cell blocks may be reduced, which eventually reduces the chip size. In addition, even when a vertical contact recess in which the source contact plug **132** is formed has a relatively small size (e.g., a width in the horizontal direction of FIG. **1**), because the sealing spacer **128** may be formed to have a relatively small thickness, the vertical contact recess may be filled with the source contact plug **132** without voids.

According to another embodiment of the present disclosure, the sealing spacer **128** may include  $\text{SiCN}$ ,  $\text{SiBCN}$ ,  $\text{SiBN}$ , or a combination thereof. The wet-etch resistance of the sealing spacer **128** may be obtained by carbon, nitrogen, boron, or a combination thereof.

According to another embodiment of the present disclosure, the sealing spacer **128** may include a stack of one or more carbon-free silicon oxide layers and one or more carbon-containing silicon oxide layers. For example, after a carbon-free silicon oxide layer (e.g.,  $\text{SiO}_2$  layer) is thinly deposited, a carbon-containing silicon oxide layer (e.g.,  $\text{SiCO}$  layer) may be deposited over the carbon-free silicon oxide layer. As a result, the carbon-containing silicon oxide layer may be in direct contact with the source contact plug **132**.

FIGS. **2**, **3**, **4**, **5**, **6**, **7**, **8**, **9**, **10**, **11**, **12**, **13**, and **14** are cross-sectional views illustrating a method for fabricating a vertical semiconductor device in accordance with an embodiment of the present disclosure. For example, FIGS. **2** to **14** show a method for fabricating the vertical semiconductor device **100** of FIG. **1**.

Referring to FIG. **2**, a first multi-layer stack **110S** may be formed over the lower structure **101**. A second multi-layer stack **120M** may be formed over the first multi-layer stack **110S**.

The first multi-layer stack **110S** may be a stack including a lower source layer **102**, a first liner layer **103**, a source sacrificial layer **104**, a second liner layer **105**, and an upper source layer **106**. According to the embodiment shown in FIG. **2**, the first multi-layer stack **110S** may have the source sacrificial layer **104** formed between the lower source layer **103** and the upper source layer **106**, the first liner layer **103** formed between the source sacrificial layer **104** and the lower source layer **102**, and the second liner layer **105** formed between the source sacrificial layer **104** and the upper source layer **106**. The lower source layer **102**, the upper source layer **106**, and the source sacrificial layer **104** may include the same material, and the first and second liner layers **103** and **105** may include a material that is different from the materials of the lower source layer **102**, the upper source layer **106**, and the source sacrificial layer **104**.

The lower source layer **102** and the upper source layer **106** may have an etch selectivity with respect to the first and second liner layers **103** and **105**. The lower source layer **102**, the upper source layer **106**, and the source sacrificial layer **104** may include a semiconductor material, and the first and second liner layers **103** and **105** may include a dielectric material. The lower source layer **102**, the upper source layer **106**, and the source sacrificial layer **104** may include polysilicon, and the first and second liner layers **103** and **105** may include silicon oxide. The first and second liner layers **103** and **105** may be thinner than the lower source layer **102**, the upper source layer **106**, and the source sacrificial layer **104**. For example, the lower source layer **102** and the upper source layer **106** may each have a thickness of approximately 150 nm in the vertical direction of FIG. **2**, and the

first and second liner layers **103** and **105** may each have a thickness of approximately 8 nm in the vertical direction. The thickness of the source sacrificial layer **104** may be the same as or thinner than the lower source layer **102** and the upper source layer **106**.

The first and second liner layers **103** and **105** may protect the lower source layer **102** and the upper source layer **106** while the source sacrificial layer **104** is removed.

The first and second liner layers **103** and **105** may include a silicon oxide-based material. One or both of the first liner layer **103** and the second liner layer **105** may include SiO<sub>2</sub>, SiCO, or a combination thereof.

The second multi-layer stack **120M** may be thicker than the first multi-layer stack **110S**. The second multi-layer stack **120M** may include a dielectric layer **111** and a sacrificial layer **112**. The second multi-layer stack **120M** may include an alternating stack of the dielectric layer **111** and the sacrificial layer **112**. The dielectric layer **111** and the sacrificial layer **112** may be alternately stacked several times. The dielectric layer **111** and the sacrificial layer **112** may include different materials. The dielectric layer **111** may have an etch selectivity with respect to the sacrificial layer **112**. The dielectric layer **111** may include silicon oxide, and the sacrificial layer **112** may include silicon nitride. The dielectric layer **111** and the sacrificial layer **112** may have substantially the same thickness. The dielectric layer **111** and the sacrificial layer **112** may be thicker than the first and second liner layers **103** and **105**, and the dielectric layer **111** and the sacrificial layer **112** may be thinner than the lower source layer **102** and the upper source layer **106**.

The dielectric layer **111** and the sacrificial layer **112** may be formed using Chemical Vapor Deposition (CVD) or Atomic Layer Deposition (ALD). An uppermost dielectric layer (or a top dielectric layer) **113** formed at a top portion of the second multi-layer stack **120M** may be attacked and damaged by the subsequent processes. Therefore, the top dielectric layer **113** may be formed thicker than the other dielectric layers **111** below the top dielectric layer **113**. The top dielectric layer **113** may be used as an etch barrier.

The first and second liner layers **103** and **105** may be thinner than the dielectric layers **111** and **113**, the lower source layer **102**, the upper source layer **106**, and the source sacrificial layer **104**. The first and second liner layers **103** and **105** may include a material that is different from those of the dielectric layers **111** and **113**. The first and second liner layers **103** and **105** may include a material having a high wet-etch resistance. The wet-etch resistance of the first and second liner layers **103** and **105** may be obtained from carbon. The first and second liner layers **103** and **105** may include a carbon-containing material, and the dielectric layers **111** and **113** may include a carbon-free material. The dielectric layers **111** and **113** may include carbon-free silicon oxide, and the first and second liner layers **103** and **105** may include carbon-containing silicon oxide. For example, the dielectric layers **111** and **113** may be SiO<sub>2</sub>, and the first and second liner layers **103** and **105** may be SiCO. SiCO may be more etch-resistant than SiO<sub>2</sub>. The carbon content of SiCO may be less than the silicon content and the oxygen content. For example, SiCO may have a composition ratio of silicon (Si) 34 at %, oxygen 40 at %, and carbon 17 at %.

The first and second liner layers **103** and **105** may be formed to have a thickness of approximately 50 Å to 100 Å. For example, each of the first and second liner layers **103** and **105** may have a thickness in a range from 50 Å to 100 Å in the vertical direction with respect to the orientation of FIG. 2. The high wet-etch resistance of SiCO may reduce the thickness of the first and second liner layers **103** and **105**.

For example, the high wet-etch resistance of SiCO may prevent the first and second liner layers **103** and **105** from being significantly etched while the source sacrificial layer **104** is removed in a wet-etch process. Thus, even when each of the first and second liner layers **103** and **105** is formed to have a relatively small thickness, the first and second liner layers **103** and **105** may protect the lower source layer **102** and the upper source layer **106**, respectively, while the source sacrificial layer **104** is removed in the wet-etch process. As a result, the height of the first multi-layer stack **110S** including the first and second liner layers **103** and **105** may be reduced.

According to another embodiment of the present disclosure, the first and second liner layers **103** and **105** may include nitrogen, boron, or a combination thereof in addition to carbon.

According to another embodiment of the present disclosure, the first and second liner layers **103** and **105** may include a stack of one or more carbon-free silicon oxide layers and one or more carbon-containing silicon oxide layers. For example, after a carbon-free silicon oxide layer is thinly deposited, a carbon-containing silicon oxide layer may be deposited over the carbon-free silicon oxide layer.

According to another embodiment of the present disclosure, the first liner layer **103** may be formed of SiO<sub>2</sub>, and the second liner layer **105** may be formed of SiCO.

According to another embodiment of the present disclosure, the stack of the second liner layer **105** and the upper source layer **106** may be replaced with one layer of SiCO.

As described above, when one or both of the first liner layer **103** and the second liner layer **105** is formed of SiCO and when the stack of the second liner layer **105** and the upper source layer **106** is replaced by one layer of SiCO, not only there is no significant loss of thickness by a wet-etch chemical, but also breakdown voltage (BV) characteristics with the source contact plug may be improved due to a small loss in the thickness of SiCO while a subsequent process of forming horizontal contact recesses and a process of expanding the horizontal contact recesses (i.e., a dry etch process and a wet-etch process for removing a blocking layer, a charge trapping layer, and a tunnel dielectric layer) are performed.

Referring to FIG. 3, a vertical opening **114** may be formed. The vertical opening **114** may be formed by etching the second multi-layer stack **120M** and partially etching the first multi-layer stack **110S** sequentially.

The vertical opening **114** may be formed substantially perpendicular to the surface (e.g., a top surface) of the lower structure **101**. The vertical opening **114** may be shaped to penetrate through the second multi-layer stack **120M** and to partially penetrate through the first multi-layer stack **110S**. Although not shown, from the perspective of a plan view, a plurality of vertical openings **114** may be formed in a hole array structure. When the vertical openings **114** are formed, the surface of the lower structure **101** may not be exposed. For example, a portion of the lower source layer **102** may remain below the bottom surface of the vertical opening **114**. The vertical opening **114** may be referred to as a vertical recess, a through hole, a vertical hole, or a channel hole.

Referring to FIG. 4, a memory stack structure **120P** may be formed in a vertical opening **114**. The memory stack structure **120P** may have a pillar shape filling the vertical opening **114**.

The memory stack structure **120P** may include a blocking layer **115**, a charge trapping layer **116**, a tunnel dielectric layer **117**, and a channel layer **118**. The memory stack structure **120P** may include an ONOP structure. The ONOP

structure may include a stack of an oxide layer, a nitride layer, an oxide layer, and a polysilicon layer. The blocking layer **115** and the tunnel dielectric layer **117** may include an oxide, and the charge trapping layer **116** may include a nitride, and the channel layer **118** may include a polysilicon layer. According to an embodiment of the present disclosure, the blocking layer **115** may include a high dielectric material, and the high dielectric material may include aluminum oxide or hafnium oxide.

The channel layer **118** may be a cylinder shape having an inner space. The tunnel dielectric layer **117** may be formed on the outer wall of the channel layer **118**, and the charge trapping layer **116** may be formed on the outer wall of the tunnel dielectric layer **117**. The blocking layer **115** may be formed on an outer wall of the charge trapping layer **116**.

The memory stack structure **120P** may further include a core dielectric layer **119**. The inner space of the channel layer **118** may be substantially completely filled with the core dielectric layer **119**. The core dielectric layer **119** may include silicon oxide or silicon nitride. Although not illustrated, a conductive pad coupled to an upper end portion of the channel layer **118** may be further formed after the core dielectric layer **119** is recessed.

The stack of the blocking layer **115**, the charge trapping layer **116**, and the tunnel dielectric layer **117** may be referred to as a memory layer, and the charge trapping layer **116** may be referred to as a memory material layer.

Referring to FIG. 5, a vertical contact recess **121** may be formed. The vertical contact recess **121** may be formed to be spaced apart from the memory stack structure **120P**. The vertical contact recess **121** may be formed by etching the second multi-layer stack **120M**, and the vertical contact recess **121** may extend downward to a portion of the first multi-layer stack **110S**. The bottom portion of the vertical contact recess **121** may penetrate through the upper source layer **106** and the second liner layer **105**. The etch process for forming the vertical contact recess **121** may stop on the upper surface of the source sacrificial layer **104**. According to another embodiment of the present disclosure, the top surface of the source sacrificial layer **104** may be partially recessed while the vertical contact recess **121** is formed. The vertical contact recess **121** may be referred to as a slit or trench. From the perspective of a top view, the vertical contact recess **121** may have a line shape extending in one direction. The vertical contact recess **121** may have a high aspect ratio perpendicular to the surface of the lower structure **101**.

Referring to FIG. 6, a sacrificial sealing layer **122** may be formed on the sidewall of the vertical contact recess **121**. The sacrificial sealing layer **122** may be formed as a spacer on the sidewall of the vertical contact recess **121**. The sacrificial sealing layer **122** may be formed by conformally forming a sacrificial sealing material layer and then performing a cutting process on the sacrificial sealing material layer.

The sacrificial sealing material layer for forming the sacrificial sealing layer **122** may include an oxide, a nitride, or a combination thereof. For example, the sacrificial sealing material layer for the sacrificial sealing layer **122** may include a first sealing layer, a second sealing layer, and a third sealing layer. The first sealing layer and the third sealing layer may include the same material, and the second sealing layer may include a material that is different from the materials of the first and third sealing layers. The second sealing layer may have an etch selectivity with respect to the first and third sealing layers. The first sealing layer and the third sealing layer may include an oxide, and the second

sealing layer may include a nitride. Thus, the sacrificial sealing layer **122** may include a NON structure. The NON structure may refer to a stack of a nitride, an oxide, and a nitride. The sacrificial sealing material layer may cover the bottom surface and sidewalls of the vertical contact recess **121**.

The sacrificial sealing material layer may be cut, and as a result, the sacrificial sealing layer **122** may be formed. The cutting process of the sacrificial sealing material layer may include an etch process, and the surface (e.g., the top surface) of the source sacrificial layer **104** may be exposed by the cutting process. After the cutting process, the sacrificial sealing material layer may remain as a spacer-type sacrificial sealing layer **122** on the sidewall of the vertical contact recess **121**. The cutting process of the sacrificial sealing material layer may include an etch-back process.

Subsequently, the source sacrificial layer **104** may be selectively removed through the vertical contact recess **121**. As a result, the horizontal contact recess **123** may be formed. The vertical contact recess **121** and the horizontal contact recess **123** may be coupled to each other. The horizontal contact recess **123** may be formed between the first liner layer **103** and the second liner layer **105** by removing the source sacrificial layer **104** through a dip-out process. The horizontal contact recess **123** may be parallel to the surface of the lower structure **101**. When the source sacrificial layer **104** is removed, the first and second liner layers **103** and **105** may have etch selectivity with respect to the source sacrificial layer **104**, and thus remain without being significantly etched. The horizontal contact recess **123** may be formed in the first multi-layer stack **110S**. When the source sacrificial layer **104** is removed, the lower source layer **102** and the upper source layer **106** may not be removed. A wet-etch process may be applied to remove the source sacrificial layer **104**. Since the source sacrificial layer **104** includes a polysilicon layer, the wet-etch process may include a chemical capable of etching the polysilicon layer.

A portion of the horizontal contact recess **123** may expose the lower sidewall of the memory stack structure **120P**. The outer wall of the memory stack structure **120P** may be a blocking layer **115**, and the blocking layer **115** of the memory stack structure **120P** may be exposed by the horizontal contact recess **123**. Since the blocking layer **115** includes an oxide, the blocking layer **115** of the memory stack structure **120P** may have etch selectivity with respect to the source sacrificial layer **104** and may not be etched while the source sacrificial layer **104** is removed. From the perspective of a top view, the horizontal contact recess **123** may have an annular shape surrounding the lower sidewall of the memory stack structure **120P**. The horizontal contact recess **123** may be referred to as a source-level air gap.

Subsequently, the first and second liner layers **103** and **105** may be removed. As a result, the height of the horizontal contact recess **123** may increase in the vertical direction with respect to the orientation of FIG. 6. The horizontal contact recess **123** having the extended height may directly contact the lower source layer **102** and the upper source layer **106**.

While the first and second liner layers **103** and **105** are removed, the blocking layer **115** of the memory stack structure **120P** may be removed. Thus, the charge trapping layer **116** of the memory stack structure **120P** may be exposed. A wet-etch process may be applied to remove the first and second liner layers **103** and **105**. The wet-etch process may include a chemical that may selectively remove silicon oxide.

Subsequently, the charge trapping layer **116** of the memory stack structure **120P** may be removed through the

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vertical contact recess **121** and the horizontal contact recess **123**. The charge trapping layer **116** may be removed by a wet-etch process. When the charge trapping layer **116** includes a nitride, the wet-etch process may include a chemical capable of etching the nitride.

By removing the charge trapping layer **116**, the horizontal length of the horizontal contact recess **123** may be increased.

Subsequently, the tunnel dielectric layer **117** of the memory stack structure **120P** may be removed through the vertical contact recess **121** and the horizontal contact recess **123**. The tunnel dielectric layer **117** may be removed by a wet-etch process. When the tunnel dielectric layer **117** includes an oxide, the wet-etch process may include a chemical capable of etching the oxide.

By removing the tunnel dielectric layer **117**, the horizontal length of the horizontal contact recess **123** may be increased.

As described above, when the process of removing the source sacrificial layer **104**, the process of removing the first and second liner layers **103** and **105**, the process of removing the blocking layer **115**, the process of removing the charge trapping layer **116**, the process of removing the tunnel dielectric layer **117** are performed, the sacrificial sealing layer **122** may serve as an etch barrier that protects the dielectric layers **111** and **113** and the sacrificial layer **112**.

A lower outer wall of the channel layer **118** of the memory stack structure **120P** may be exposed by the process of expanding the horizontal contact recess **123**. For example, an annular air gap may expose the lower outer wall of the channel layer **118**. The annular air gap may refer to portions from which the blocking layer **115**, the charge trapping layer **116**, and the tunnel dielectric layer **117** are removed.

The first multi-layer stack in which one or more horizontal contact recesses **123** are formed may be denoted by **110S'**.

By the series of the processes illustrated in FIGS. **2** to **6**, a contact opening penetrating through the first multi-layer stack **110S'** and the second multi-layer stack **120M** may be formed. The contact opening may include a vertical contact recess **121** and a horizontal contact recess **123**. The horizontal contact recess **123** may extend from the vertical contact recess **121**. The vertical contact recess **121** may extend in a direction (e.g., a vertical direction) perpendicular to the surface (e.g., the top surface) of the lower structure **101**, and the horizontal contact recess **123** may extend in a direction (e.g., a horizontal direction) parallel to the surface of the lower structure **101**. The horizontal contact recess **123** may have a high aspect ratio that is parallel to the surface of the lower structure **101**. For example, the horizontal contact recess **123** may have a relatively high ratio of the width in the horizontal direction over the height in the vertical direction. The vertical contact recess **121** may have a high aspect ratio perpendicular to the lower structure **101**. For example, the vertical contact recess **121** may have a relatively high ratio of the height in the vertical direction over the width in the horizontal direction.

Referring to FIG. **7**, a source contact material **124A** may be formed to fill a contact opening, for example, the vertical recess **121** and the horizontal contact recess **123**. The source contact material **124A** may include a conductive material. The source contact material **124A** may include polysilicon. The source contact material **124A** may include polysilicon which is doped with phosphorus (P). The source contact material **124A** may include polysilicon containing carbon. The source contact material **124A** may include a stack of phosphorus-doped polysilicon (SiP) and carbon-doped polysilicon (SiC).

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Subsequently, the source contact material **124A** may be selectively removed. The process of selectively removing the source contact material **124A** may include a recessing process, and the recessing process may include a wet-etch process. The source contact layer **124** may be formed in the horizontal contact recess **123** by performing the wet-etching process on the source contact material **124A**. The source contact layer **124** may fill the horizontal contact recess **123**. For example, the source contact material **124A** may be etched using the sidewalls of the sacrificial sealing layer **122** to make the source contact layer **124** self-aligned with the sidewalls of the sacrificial sealing layer **122**. As a result, the bottom surface of the vertical recess **121** may directly contact the lower source layer **102**. The source contact layer **124** may remain in the horizontal contact recess **123**, and the source contact layer **124** may not remain in the vertical recess **121**.

Although not illustrated, the source contact layer **124** may be exposed to an oxidation process subsequently. The oxidation process may include a dry oxidation process or a wet oxidation process. An edge of the source contact layer **124** may be oxidized by an oxidation process. As a result, a barrier oxide (not shown) may be formed at the edge of the source contact layer **124** (that is, the portion exposed by the bottom portion of the vertical contact recess **121**). The barrier oxide may include silicon oxide. The barrier oxide may protect the source contact layer **124** from being attacked during the subsequent process.

The first multi-layer stack **110S'** in which the source contact layer **124** is formed may be simply referred to as a source-level stack **110**. The source-level stack **110** may be disposed below the second multi-layer stack **120M**, and the source contact layer **124** may be directly coupled to the channel layer **118** of the memory stack structure **120P**.

As described above, the source-level stack **110** which is formed by a series of the processes of replacing the source sacrificial layer **104** with the source contact layer **124** may have a structure in which the source contact layer **124** is embedded.

Referring to FIGS. **8** to **10**, the sacrificial layers **112** may be replaced with the gate electrodes **127**.

As shown in FIG. **8**, the sacrificial layers **112** of the second multi-layer stack **120M** may be selectively removed. As a result, the horizontal gate recesses **125** may be formed between the dielectric layers **111**. Since the sacrificial layer **112** includes a nitride, the sacrificial layer **112** may be removed by a chemical including a phosphoric acid ( $H_3PO_4$ ). While the sacrificial layer **112** is removed, the sacrificial sealing layer **122** may also be removed at the same time.

According to another embodiment of the present disclosure, the sacrificial sealing layer **122** may be removed after the sacrificial layer **112** is removed.

While the sacrificial layer **112** is removed, the source contact layer **124** may be sufficiently protected by a barrier oxide. The barrier oxide may serve as a protective layer for protecting the source contact layer **124** from being attacked.

The horizontal gate recesses **125** may be continuous from the vertical contact recess **121**. Portions of the blocking layer **115** of the memory stack structure **120P** may be exposed by the horizontal gate recesses **125**.

After the horizontal gate recesses **125** are formed in the second multi-layer stack **120M** in FIG. **7**, a first intermediate multi-layer stack **120'** may be formed. The first intermediate multi-layer stack **120'** may have a structure in which the dielectric layers **111** and the horizontal gate recesses **125**

alternate. A horizontal gate recess **125** may also be formed between the top dielectric layer **113** and a neighboring dielectric layer **111**.

Referring to FIGS. **9** and **10**, the gate electrodes **127** may fill the horizontal gate recesses **125**, respectively. The gate electrode **127** may be formed by forming a gate material layer **126** to fill the horizontal gate recesses **125** (see FIG. **9**). After the gate material layer **126** is formed, a second intermediate multi-layer stack **120"** may be formed. The second intermediate multi-layer stack **120"** may have a structure in which the dielectric layers **111** and the gate material **126** alternate. The gate material **126** may cover the sidewall of the vertical contact recess **121**.

Subsequently, as illustrated in FIG. **10**, gate electrodes **127** may be formed by performing an etch-back process on the gate material layer **126**. The gate electrodes **127** may include a low-resistance material. The gate electrodes **127** may include a metal-based material. The gate electrodes **127** may include a metal, a metal silicide, a metal nitride, or a combination thereof. For example, the metal may include nickel, cobalt, platinum, titanium, tantalum, or tungsten. The metal silicide may include nickel silicide, cobalt silicide, platinum silicide, titanium silicide, tantalum silicide, or tungsten silicide. The gate electrodes **127** may include a stack of titanium nitride and tungsten.

The ends **127R** of the gate electrodes **127** may have a shape that is horizontally recessed from the ends of the dielectric layers **111**. The ends **127R** of the gate electrodes **127** may be exposed by the vertical contact recess **121**. The gate electrodes **127** may not contact the upper source layer **106**, the lower source layer **102**, and the source contact layer **124**.

After the gate electrodes **127** are formed, an alternating stack **120** may be formed. The alternating stack **120** may have a structure in which the dielectric layers **111** and the gate electrodes **127** are alternately stacked. The memory stack structure **120P** may penetrate through the alternating stack **120**, and the vertical contact recess **121** may penetrate through the alternating stack **120**.

Referring to FIG. **11**, the surface of the vertical contact recess **121** may be sealed. The surface of the vertical contact recess **121** may be sealed by the sealing layer **128S**. The sealing layer **128S** may include one or more protrusions **128P**, and the protrusions **128P** may seal the ends **127R** of the gate electrodes **127**. The sealing layer **128S** may seal the side surfaces of the dielectric layers **111** and **113**. The sealing layer **128S** may seal the side surface of the source contact layer **124**. The sealing layer **128S** may seal the side surface of the upper source layer **106** and may seal the exposed surface of the lower source layer **102**. The sealing layer **128S** may include a silicon oxide-based material. The sealing layer **128S** may include a low-dielectric material. The low-dielectric material may have a lower dielectric constant than silicon nitride. The material of the sealing layer **128S** may have a dielectric constant lower than approximately 7.

The sealing layer **128S** may be thinner than the dielectric layers **111** and **113** and the gate electrode **127**. The sealing layer **128S** may be a layer of a material that is different from that of the dielectric layers **111** and **113**. The sealing layer **128S** may be a layer of a material that is different from that of the gate electrode **127**. The sealing layer **128S** may include a material having high wet-etch resistance. The wet-etch resistance of the sealing layer **128S** may be obtained by carbon. The sealing layer **128S** may be formed of a carbon-containing material, and the dielectric layers **111** and **113** may be formed of a carbon-free

silicon oxide, and the sealing layer **128S** may be formed of carbon-containing silicon oxide. For example, the dielectric layers **111** and **113** may be formed of SiO<sub>2</sub>, and the sealing layer **128S** may be formed of SiCO. SiCO may be more etch-resistant than SiO<sub>2</sub>. The carbon content in SiCO may be less than the silicon content and the oxygen content. For example, SiCO may have a composition ratio of silicon (Si) 34 at %, oxygen 40 at %, and carbon 17 at %. SiCO may have a lower dielectric constant than silicon nitride (Si<sub>3</sub>N<sub>4</sub>).

The sealing layer **128S** may be formed to a thickness of approximately 50 Å to 100 Å. The high wet-etch resistance of SiCO may reduce the thickness of the sealing layer **128S**. As a result, the size of the vertical contact recess **121** for separating cell blocks may be reduced, which may reduce the chip size. In a comparative example, when a sealing layer is formed of SiO<sub>2</sub>, the sealing layer should be formed to have a thickness of approximately 150 Å or more in consideration of loss in the subsequent processes (e.g., a cleaning process), and the thick SiO<sub>2</sub> may inhibit a vertical contact recess from being filled with a source contact plug without voids. In order to improve the gapfill characteristics of the source contact plug, the vertical contact recess in the comparative example should be formed to have a relatively large size. In contrast, since SiCO of the sealing layer **128S** in the embodiment of the present disclosure has greater wet-etch resistance than SiO<sub>2</sub>, the sealing layer **128S** of SiCO may be formed thinner than the sealing layer of SiO<sub>2</sub> in the comparative example. Therefore, even though the size of the vertical contact recess **121** is small, a source contact plug may fill the vertical contact recess **121** without voids.

According to another embodiment of the present disclosure, the sealing layer **128S** may include a material that is wet-etch resistant to the subsequent processes. The sealing layer **128S** may include SiCN, SiBCN, SiBN, or a combination thereof. The wet-etch resistance of the sealing layer **128S** may be obtained from carbon, nitrogen, boron, or a combination thereof.

According to another embodiment of the present disclosure, a seed layer may be formed prior to the formation of the sealing layer **128S**. The seed layer may form a thin silicon oxide or silicon nitride. By forming the seed layer, the conformality of the sealing layer **128S** may be improved.

According to another embodiment of the present disclosure, the sealing layer **128S** may include a stack of one or more carbon-free silicon oxide layers and one or more carbon-containing silicon oxide layers. For example, after a carbon-free silicon oxide layer is thinly deposited, a carbon-containing silicon oxide layer may be deposited over the carbon-free silicon oxide layer. The carbon-free silicon oxide may improve the conformality of the carbon-containing silicon oxide as the seed layer.

Although not illustrated, the sealing layer **128S** may seal the upper surface of the top dielectric layer **113**.

Referring to FIG. **12**, the sealing layer **128S** may be selectively removed to expose the surface of the lower source layer **102**. As a result, a sealing spacer **128** may be formed on the sidewall of the vertical contact recess **121**. The bottom portion of the sealing spacer **128** may substantially completely cover the side of the source contact layer **124** and the side of the upper source layer **106**. The sealing spacer **128** may include one or more protrusions **128P**, and the protrusions **128P** may seal the ends **127R** of the gate electrodes **127**. The sealing spacer **128** may seal the sides of the dielectric layers **111** and **113**.

The sealing spacer **128** may be vertically continuous along the stacking direction of the dielectric layers **111** and **113** and the gate electrodes **127**. From the perspective of a

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top view, the sealing spacer 128 may be a closed loop-shape sealing the sidewall of the vertical contact recess 121.

Since the thickness of the sealing layer 128S is thin, the open area of the bottom surface of the vertical contact recess 121 may be increased in an etch process for forming the sealing spacer 128. As a result, it is possible to secure an electrically low resistance and process stability.

After the sealing spacer 128 is formed, a post-cleaning process may be performed.

Referring to FIGS. 13 and 14, the vertical contact recess 121 may be filled with a contact material. For example, a source contact plug 132 may be formed in the vertical contact recess 121. The source contact plug 132 may fill the vertical contact recess 121. The source contact plug 132 may include a stack of a silicon-containing material 129 and a metal-containing material 131, and may further include a barrier material 130 between the silicon-containing material 129 and the metal-containing material 131. The silicon-containing material 129 may include polysilicon, and the metal-containing material 131 may include tungsten. The barrier material 130 may include titanium nitride. According to another embodiment of the present disclosure, the source contact plug 132 may be formed of tungsten alone.

The silicon-containing material 129 may be formed by depositing polysilicon to fill the vertical contact recess 121 and performing an etch-back process onto the polysilicon. A pre-cleaning process may be performed before the deposition of polysilicon, and a post-cleaning process may be performed after the etch-back process of the polysilicon. The silicon-containing material 129 may be in contact with the sealing spacer 128.

After the silicon-containing material 129 is formed, the barrier material 130 may be conformally deposited. A pre-cleaning process may be performed before the deposition of the barrier material 130. After the barrier material 130 is conformally deposited, the remainder of the vertical contact recess 121 may be filled with the metal-containing material 131. After the barrier material 130 and the metal-containing material 131 are sequentially deposited, a planarization process using Chemical Mechanical Polishing (CMP) may be performed. As a result, the barrier material 130 and the metal-containing material 131 may remain only in the vertical contact recess 121. The barrier material 130 may be in direct contact with the sealing spacer 128, and the metal-containing material 131 may not contact the sealing spacer 128.

Although a plurality of cleaning processes are performed during the process of forming the sealing spacer 128, the process of forming the silicon-containing material 129, and the process of depositing the barrier material 130, the thickness loss of the sealing spacer 128 may hardly occur.

As described above, the source-level stack 110 and the alternating stack 120 may be formed over the lower structure 101. The source-level stack 110 may include the lower source layer 102, the source contact layer 124, and the upper source layer 106. The alternating stack 120 may be formed by alternately stacking the dielectric layers 111 and the gate electrodes 127. The memory stack structure 120P may penetrate through the alternating stack 120 and the source-level stack 110. The lower outer wall of the channel layer 118 of the memory stack structure 120P may directly contact the source contact layer 124. The channel layer 118, the lower source layer 102, the upper source layer 106, and the source contact plug 132 may be electrically connected through the source contact layer 124.

The gate electrodes 127 and the source contact plug 132 may be electrically disconnected from each other by the

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sealing spacer 128. The gate electrodes 127 and the source contact plug 132 may be physically disconnected by the sealing spacer 128. A high voltage may be repeatedly applied between the gate electrode 127 and the source contact plug 132, thereby increasing Grown Bad Blocks (GBB). The GBB is a phenomenon that as the number of operations is increased, the number of bad blocks may be increased. According to the embodiment of the present disclosure, the sealing spacer 128 may include the carbon-containing material, thereby preventing GBB defects. In other words, since the sealing spacer 128 is formed of a material having a high wet-etch resistance, the thickness loss of the sealing spacer 128 may not substantially occur during the subsequent cleaning processes, and thus the sealing spacer 128 may be secured with a thickness that is thick enough to withstand the high voltage applied between the gate electrode 127 and the source contact plug 132.

Also, since the sealing spacer 128 is formed of a low dielectric material according to the embodiment of the present disclosure, the parasitic capacitance between the gate electrodes 127 and the source contact plug 132 may be relatively small.

Referring to FIGS. 2 to 14, a method for fabricating a vertical semiconductor device may include: forming the first multi-layer stack 110S that includes the sacrificial source layer 104 over the lower structure 101; forming the second multi-layer stack 120M in which the dielectric layers 111 and the sacrificial layers 112 are alternately stacked over the first multi-layer stack 110S; forming the memory stack structure 120P that includes the channel layer 118 extending through the second multi-layer stack 120M and the first multi-layer stack 110S; forming the vertical contact recess 121 to be spaced apart from the memory stack structure 120P and to extend through the second multi-layer stack 120M and the first multi-layer stack 110S; forming the horizontal contact recess 123 by selectively removing the sacrificial source layer 104 through the vertical contact recess 121; expanding the horizontal contact recess 123 to expose the lower outer wall of the channel layer 118; filling the expanded horizontal contact recess 123 with the source contact layer 124; replacing the sacrificial layers 112 with the gate electrodes 127; forming the sealing spacer 128 that seals the sidewall of the vertical contact recess 121 over the source contact layer 124 and the gate electrodes 127; and forming the source contact plug 132 in the vertical contact recess 121. The sealing spacer 128 may be formed of carbon-containing silicon oxide.

FIG. 15 is a cross-sectional view illustrating a vertical semiconductor device 200 in accordance with another embodiment of the present disclosure.

Referring to FIG. 15, the vertical semiconductor device 200 may be positioned over the lower structure 101, and the vertical semiconductor device 200 may include an alternating stack 120 in which gate electrodes 127 and dielectric layers 111 are alternately stacked, a memory stack structure 120P including a channel layer 118 extending to penetrate through the alternating stack 120 and a stack of layers (or a memory layer) 115, 116, and 117 surrounding the channel layer 118, a source contact layer 124 disposed between the lower structure 101 and the alternating stack 120 to contact the lower outer wall of the channel layer 118, and a source contact plug 132 extending through the alternating stack 120 to be spaced apart from the memory stack structure 120P, and a sealing spacer 128 having an etch resistance that is different from the etch resistance of the dielectric layers 111 while sealing the outer wall of the source contact plug. The sealing spacer 128 may seal the gate electrodes 127 and be



disposed between the source contact plug 132 and the gate electrodes 127, and may have an etch resistance that is different from that of the dielectric layers 111. The outer wall of the source contact plug 132 may be surrounded by the sealing spacer 128, which may vertically extend to cover the gate electrodes 127, the dielectric layers 111, a carbon-containing liner layer 105', and the source contact layer 124.

The lower structure 101 may include a material suitable for semiconductor processing. The lower structure 101 may include a substrate, and the substrate may include a semiconductor substrate. For example, the lower structure 101 may include a silicon substrate, a monocrystalline silicon substrate, a polysilicon substrate, an amorphous silicon substrate, a silicon germanium substrate, a monocrystalline silicon germanium substrate, a polycrystalline silicon germanium substrate, a carbon-doped silicon substrate, a combination thereof, or a multilayer thereof. The lower structure 101 may include other semiconductor materials, such as germanium. The lower structure 101 may include a III/V-group semiconductor substrate, such as a compound semiconductor substrate, e.g., GaAs. The lower structure 101 may include a silicon on insulator (SOI) substrate. Although not shown, according to another embodiment of the present disclosure, the lower structure 101 may include a substrate, at least one or more control circuits formed over the substrate, and a multi-layer metal line.

A multi-layer stack structure may be disposed over the lower structure 101 and include a source-level stack 110 and an alternating stack 120 over the source-level stack 110. The source-level stack 110 may have a lower height than the alternating stack 120.

The source-level stack 110 may include a lower source layer 102, a source contact layer 124, and a carbon-containing liner layer 105'. The source contact layer 124 may be formed over the lower source layer 102, and the carbon-containing liner layer 105' may be formed over the source contact layer 124. The source contact layer 124 may be disposed between the lower source layer 102 and the carbon-containing liner layer 105'. The lower source layer 102 and the source contact layer 124 may include a semiconductor material. The lower source layer 102 and the source contact layer 124 may include polysilicon. The source contact layer 124 may include polysilicon doped with phosphorus (P). The source contact layer 124 may include carbon-containing polysilicon. The source contact layer 124 may include a stack of phosphorus-doped polysilicon (SiP) and carbon-doped polysilicon (SiC). The lower source layer 102 may include undoped polysilicon or doped polysilicon.

The carbon-containing liner layer 105' may include a silicon oxide-based material. The carbon-containing liner layer 105' may include at least SiCO.

The carbon-containing liner layer 105' may be a layer of a material that is different from those of the dielectric layers 111 and 113. The carbon-containing liner layer 105' may include a material having a high wet-etch resistance. The wet-etch resistance of the carbon containing liner layer 105' may be obtained from carbon. The carbon-containing liner layer 105' may be a carbon-containing material, and the dielectric layers 111 and 113 may be a carbon-free material. The dielectric layers 111 and 113 may be carbon-free silicon oxide, and the carbon-containing liner layer 105' may be carbon-containing silicon oxide. For example, the dielectric layers 111 and 113 may be SiO<sub>2</sub> and the carbon-containing liner layer 105' may be SiCO. SiCO may be more etch-resistant than SiO<sub>2</sub>. The carbon content in SiCO may be smaller than the silicon content and the oxygen content. For

example, SiCO may have a composition ratio of silicon (Si) 34 at %, oxygen 40 at %, and carbon 17 at %.

The carbon-containing liner layer 105' may be formed to a thickness of approximately 50 Å to 100 Å. For example, the carbon-containing liner layer 105' may have a thickness in a range from 50 Å to 100 Å in the vertical direction with respect to the orientation of FIG. 15. The high wet-etch resistance of SiCO may reduce the thickness of the carbon-containing liner layer 105'. As a result, the height of the source-level stack 110 may be reduced. The bottom dielectric layer 111 among the dielectric layers 111 may have a thickness that is thinner than each of the dielectric layers 111 at a higher level than the bottom dielectric layer 111. For example, when the carbon-containing liner layer 105' is formed of SiCO, the thickness of the bottom dielectric layer 111 may be relatively thin (e.g., approximately 200 Å). As a result, a dopant diffusion movement distance from the source contact layer 124 to the channel layer 118 adjacent to the bottom gate electrode 127 may be shortened. The dielectric layers 111 at a higher level than the bottom dielectric layer 111 may be approximately 300 Å thick.

According to another embodiment of the present disclosure, the carbon-containing liner layer 105' may be replaced with a material containing nitrogen, boron, or a combination thereof in addition to carbon.

The alternating stack 120 may be called a memory cell stack or a memory cell string. The alternating stack 120 may have a structure in which a plurality of dielectric layers 111 and a plurality of gate electrodes 127 are alternately stacked. The uppermost dielectric layer 113 among the dielectric layers 111 may be thicker than the other dielectric layers 111. The dielectric layers 111 may include silicon oxide. The gate electrodes 127 may include a low-resistance material. The gate electrodes 127 may include a metal-based material. The gate electrodes 127 may include a metal, a metal silicide, a metal nitride, or a combination thereof. For example, the metal may include nickel, cobalt, platinum, titanium, tantalum, or tungsten. The metal silicide may include nickel silicide, cobalt silicide, platinum silicide, titanium silicide, tantalum silicide or tungsten silicide. The gate electrodes 127 may include a stack of titanium nitride and tungsten. The ends (e.g., ends 127R in FIG. 24) of the gate electrodes 127 may have a shape that is horizontally recessed from the ends of the dielectric layers 111.

The memory stack structure 120P may extend vertically to penetrate through the alternating stack 120. The memory stack structure 120P may have a pillar shape. The memory stack structure 120P may include a blocking layer 115, a charge trapping layer 116, a tunnel dielectric layer 117, a channel layer 118, and a core dielectric layer 119. The memory stack structure 120P may include an ONOP structure. The ONOP structure may include a stack of an oxide layer, a nitride layer, an oxide layer, and a polysilicon layer. The blocking layer 115 and the tunnel dielectric layer 117 may include an oxide, and the charge trapping layer 116 may include a nitride, and the channel layer 118 may include polysilicon. According to an embodiment of the present disclosure, the blocking layer 115 may include a high dielectric material, and the high dielectric material may include aluminum oxide or hafnium oxide. The channel layer 118 may be a cylindrical shape having an inner space. The tunnel dielectric layer 117 may be formed on the outer wall of the channel layer 118, and the charge trapping layer 116 may be formed on the outer wall of the tunnel dielectric layer 117. The blocking layer 115 may be formed on the outer wall of the charge trapping layer 116. The inner space of the channel layer 118 may be substantially completely

filled with the core dielectric layer 119. The core dielectric layer 119 may include silicon oxide or silicon nitride. The stack of the blocking layer 115, the charge trapping layer 116, and the tunnel dielectric layer 117 may be called a memory layer 115/116/117.

The source contact plug 132 may include a stack of a silicon-containing material 129 and a metal-containing material 131, and it may further include a barrier material 130 between the silicon-containing material 129 and the metal-containing material 131. The silicon-containing material 129 may include polysilicon, and the metal-containing material 131 may include tungsten. The barrier material 130 may include titanium nitride. According to another embodiment of the present disclosure, the source contact plug 132 may be formed of tungsten alone. The lower portion of the source contact plug 132 may be coupled to the lower source layer 102 of the source-level stack 110.

The sealing spacer 128 may be formed between the source contact plug 132 and the gate electrodes 127. The sealing spacer 128 may extend to be formed between the dielectric layers 111 and 113 and the source contact plug 132. The sealing spacer 128 may be continuous along the stacking direction of the alternating stack 120. The sealing spacer 128 may include one or more protrusions 128P, and the protrusions 128P may be coupled to the ends of the gate electrodes 127, respectively. The protrusions 128P of the sealing spacer 128 may seal the ends of the gate electrodes 127. The sealing spacer 128 may seal the sides of the dielectric layers 111 and 113. The sealing spacer 128 may seal the side of the source contact layer 124. The sealing spacer 128 may seal the side of the carbon-containing liner layer 105' and may not seal a portion of the surface of the lower source layer 102. The sealing spacer 128 may substantially fully surround the outer wall of the source contact plug 132.

The sealing spacer 128 may include a silicon oxide-based material. The sealing spacer 128 may include a low dielectric material. The low dielectric material may have a lower dielectric constant than silicon nitride. The sealing spacer 128 may have a dielectric constant lower than approximately 7. The sealing spacer 128 may be thinner than the dielectric layers 111 and 113 and the gate electrodes 127. The sealing spacer 128 may be a layer of a material that is different from those of the dielectric layers 111 and 113. The sealing spacer 128 may be a layer of a material that is different from that of the gate electrodes 127. The carbon-containing liner layer 105' and the sealing spacer 128 may include the same material. The sealing spacer 128 may include a material having a high wet-etch resistance. The wet-etch resistance of the sealing spacer 128 may be obtained from carbon. The sealing spacer 128 may include a carbon-containing material, and the dielectric layers 111 and 113 may include a carbon-free material. The dielectric layers 111 and 113 may be formed of carbon-free silicon oxide, and the sealing spacer 128 may be formed of carbon-containing silicon oxide. For example, the dielectric layers 111 and 113 may be formed of SiO<sub>2</sub>, and the sealing spacer 128 may be formed of SiCO. SiCO may be more etch-resistant than SiO<sub>2</sub>. The carbon content of SiCO may be less than the silicon content and the oxygen content of SiCO. For example, SiCO may have a composition ratio of silicon (Si) 34 at %, oxygen 40 at %, and carbon 17 at %. SiCO may have a lower dielectric constant than silicon nitride (Si<sub>3</sub>N<sub>4</sub>).

The sealing spacer 128 may be formed to have a thickness of approximately 50 Å to 100 Å. The high wet-etch resistance of SiCO may reduce the thickness of the sealing spacer 128. As a result, the size of the source contact plug 132 for separating cell blocks may be reduced, and thus the chip size

may be reduced. The sealing spacer 128 may be thinner than the carbon-containing liner layer 105'.

According to another embodiment of the present disclosure, the sealing spacer 128 may include SiCN, SiBCN, SiBN, or a combination thereof. The wet-etch resistance of the sealing spacer 128 may be obtained from carbon, nitrogen, boron, or a combination thereof.

According to another embodiment of the present disclosure, the sealing spacer 128 may include a stack of one or more carbon-free silicon oxide layers and one or more carbon-containing silicon oxide layers. For example, after thinly depositing a carbon-free silicon oxide layer, a carbon-containing silicon oxide layer may be deposited over the carbon-free silicon oxide layer.

FIGS. 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, and 28 are cross-sectional views illustrating a method for fabricating a vertical semiconductor device in accordance with another embodiment of the present disclosure. For example, FIGS. 16 to 28 show a method for fabricating the vertical semiconductor device 200 of FIG. 5.

Referring to FIG. 16, a first multi-layer stack 110S may be formed over the lower structure 101. The first multi-layer stack 110S may have a stack structure including a lower source layer 102, a first liner layer 103, a source sacrificial layer 104, and a second liner layer 105'. In the first multi-layer stack 110S according to the embodiment shown in FIG. 16, a first liner layer 103 may be formed between the lower source layer 102 and the source sacrificial layer 104, and a second liner layer 105' may be formed over the source sacrificial layer 104. The lower source layer 102 and the source sacrificial layer 104 may include the same material, and the first and second liner layers 103 and 105' may include a material that is different from the materials of the lower source layer 102 and the source sacrificial layer 104. The first and second liner layers 103 and 105' may have an etch selectivity with respect to the source sacrificial layer 104. The lower source layer 102 and the source sacrificial layer 104 may include a semiconductor material, and the first and second liner layers 103 and 105' may include a dielectric material. The lower source layer 102 and the source sacrificial layer 104 may include polysilicon, and the first and second liner layers 103 and 105' may include silicon oxide. The source sacrificial layer 104 may have the same thickness or thinner thickness than the lower source layer 102 and the second liner layer 105'. The second liner layer 105' may be thicker than the first liner layer 103.

The first and second liner layers 103 and 105' may protect the lower source layer 102 while the source sacrificial layer 104 is removed.

The first and second liner layers 103 and 105' may include a silicon oxide-based material. One or both of the first liner layer 103 and the second liner layer 105' may include SiO<sub>2</sub>, SiCO, or a combination thereof.

The second liner layer 105' may be a layer of a material that is different from the material of the first liner layer 103. The second liner layer 105' may include a material having high wet-etch resistance. The wet-etch resistance of the second liner layer 105' may be obtained from carbon. The second liner layer 105' may include a carbon-containing material, and the first liner layer 103 may include a carbon-free material. The first liner layer 103 may be formed of a carbon-free silicon oxide, and the second liner layer 105' may be formed of a carbon-containing silicon oxide. For example, the first liner layer 103 may be formed of SiO<sub>2</sub>, and the second liner layer 105' may be formed of SiCO. SiCO may be more etch-resistant than SiO<sub>2</sub>. The carbon content of SiCO may be less than the silicon content and the oxygen

content of SiCO. For example, SiCO may have a composition ratio of silicon (Si) 34 at %, oxygen 40 at %, and carbon 17 at %.

The first and second liner layers **103** and **105'** may be formed to have a thickness of approximately 50 Å to 100 Å. The high wet-etch resistance of SiCO may reduce the thickness of the second liner layer **105'**. As a result, the height of the first multi-layer stack **110S** may be reduced.

According to another embodiment of the present disclosure, the second liner layer **105'** may include nitrogen, boron, or a combination thereof in addition to carbon.

As described above, the first liner layer **103** may be formed of SiO<sub>2</sub>, and the second liner layer **105'** may be formed of SiCO. Unlike FIG. 2, in FIG. 16, the upper source layer **106** may be omitted, and only the second liner layer **105'** may be formed. The second liner layer **105'** has a smaller thickness than a thickness of the upper source layer **106**.

Subsequently, a second multi-layer stack **120M** may be formed over the first multi-layer stack **110S**. The second multi-layer stack **120M** may be thicker than the first multi-layer stack **110S**. The second multi-layer stack **120M** may include a dielectric layer **111** and a sacrificial layer **112**. The second multi-layer stack **120M** may include an alternating stack of the dielectric layer **111** and the sacrificial layer **112**. The dielectric layer **111** and the sacrificial layer **112** may be alternately stacked several times. The dielectric layer **111** and the sacrificial layer **112** may include different materials. The dielectric layer **111** may have an etch selectivity with respect to the sacrificial layer **112**. The dielectric layer **111** may include silicon oxide, and the sacrificial layer **112** may include silicon nitride. The dielectric layer **111** and the sacrificial layer **112** may have substantially the same thickness.

The dielectric layer **111** and the sacrificial layer **112** may be formed by Chemical Vapor Deposition (CVD) or Atomic Layer Deposition (ALD). An uppermost dielectric layer (or a top dielectric layer) **113** formed at a top portion of the second multi-layer stack **120M** may be attacked and damaged by the subsequent processes. Therefore, the top dielectric layer **113** may be formed thicker than that of the dielectric layers **111** disposed under the top dielectric layer **113**. The top dielectric layer **113** may be used as an etch barrier. A lowermost dielectric layer (or a bottom dielectric layer) **111** in contact with the second liner layer **105'** among the dielectric layers **111** may be thinner than other dielectric layers **111** over the bottom dielectric layer **111**. For example, when the second liner layer **105'** is formed of SiCO, the thickness of the lowermost dielectric layer **111** may be formed thin (e.g., approximately 200 Å). The other dielectric layers **111** over the bottom dielectric layer **111** may have a thickness of approximately 300 Å.

Referring to FIG. 17, a vertical opening **114** may be formed. The vertical opening **114** may be formed by etching the second multi-layer stack **120M** and partially etch the first multi-layer stack **110S** sequentially.

The vertical opening **114** may be formed substantially perpendicular to the surface (e.g., a top surface) of the lower structure **101**. The vertical opening **114** may be shaped to penetrate through the second multi-layer stack **120M**, or it may be shaped to partially penetrate through the first multi-layer stack **110S**. Although not shown, from the perspective of a plan view, the vertical openings **114** may be formed in plural, and may have a hole array structure. When the vertical opening **114** is formed, the surface of the lower structure **101** may not be exposed. For example, a portion of the lower source layer **102** may remain below the bottom of

the vertical opening **114**. The vertical opening **114** may be called a vertical recess, a vertical hole, or a channel hole.

Referring to FIG. 18, a memory stack structure **120P** may be formed in the vertical opening **114**. The memory stack structure **120P** may have a pillar shape that fills the vertical opening **114**.

The memory stack structure **120P** may include a blocking layer **115**, a charge trapping layer **116**, a tunnel dielectric layer **117**, and a channel layer **118**. The memory stack structure **120P** may include an ONOP structure. The ONOP structure may include a stack of an oxide layer, a nitride layer, an oxide layer, and a polysilicon layer. The blocking layer **115** and the tunnel dielectric layer **117** may include an oxide, the charge trapping layer **116** may include a nitride, and the channel layer **118** may include a polysilicon layer. According to an embodiment of the present disclosure, the blocking layer **115** may include a high dielectric material, and the high dielectric material may include aluminum oxide or hafnium oxide.

The channel layer **118** may have a cylindrical shape having an inner space. A tunnel dielectric layer **117** may be formed on the outer wall of the channel layer **118**, and a charge trapping layer **116** may be formed on the outer wall of the tunnel dielectric layer **117**. The blocking layer **115** may be formed on the outer wall of the charge trapping layer **116**.

The memory stack structure **120P** may further include a core dielectric layer **119**. The inner space of the channel layer **118** may be substantially completely filled with the core dielectric layer **119**. The core dielectric layer **119** may include silicon oxide or silicon nitride. Although not illustrated, a conductive pad coupled to the upper end of the channel layer **118** may be further formed after the core dielectric layer **119** is recessed.

The stack of the blocking layer **115**, the charge trapping layer **116**, and the tunnel dielectric layer **117** may be referred to as a memory layer, and the charge trapping layer **116** may be referred to as a memory material layer.

Referring to FIG. 19, a vertical contact recess **121** may be formed. The vertical contact recess **121** may be formed to be spaced apart from the memory stack structure **120P**. The vertical contact recess **121** may be formed by etching the second multi-layer stack **120M**, and the vertical contact recess **121** may extend downward to a portion of the first multi-layer stack **110S**. The bottom portion of the vertical contact recess **121** may penetrate through the second liner layer **105'**. The etch process for forming the vertical contact recess **121** may stop at the source sacrificial layer **104**. According to another embodiment of the present disclosure, the top surface of the source sacrificial layer **104** may be partially recessed during the vertical contact recess **121** is formed. The vertical contact recess **121** may be referred to as a slit or trench. From the perspective of a top view, the vertical contact recess **121** may have a line shape extending in one direction. The vertical contact recess **121** may have a high aspect ratio perpendicular to the surface of the lower structure **101**.

Referring to FIG. 20, a sacrificial sealing layer **122** may be formed on the sidewall of the vertical contact recess **121**. The sacrificial sealing layer **122** may be formed as a spacer on the sidewall of the vertical contact recess **121**. The sacrificial sealing layer **122** may be formed by conformally forming a sacrificial sealing material layer and then performing a cut process on the sacrificial sealing material layer.

The sacrificial sealing material layer for forming the sacrificial sealing layer **122** may include an oxide, a nitride,

or a combination thereof. For example, the sacrificial sealing material layer, which includes a combination of an oxide and a nitride, may include a first sealing layer, a second sealing layer, and a third sealing layer. The first sealing layer and the third sealing layer may include the same material, and the second sealing layer may include a material that is different from those of the first and third sealing layers. The second sealing layer may have an etch selectivity with respect to the first and third sealing layers. The first sealing layer and the third sealing layer may include an oxide, and the second sealing layer may include a nitride. Thus, the sacrificial sealing layer **122** may include a NON structure. The NON structure may refer to a stack of a nitride, an oxide, and a nitride. The sacrificial sealing material layer may cover the bottom and sidewalls of the vertical contact recess **121**.

The sacrificial sealing material layer may go through a cutting process, and as a result, the sacrificial sealing layer **122** may be formed. The cutting process of the sacrificial sealing material layer may include an etch process, and the surface (e.g., the top surface) of the source sacrificial layer **104** may be exposed as a result of the cutting process. After the cutting process, the sacrificial sealing material layer may remain as a spacer-type sacrificial sealing layer **122** on the sidewall of the vertical contact recess **121**. The cutting process of the sacrificial sealing material layer may include an etch-back process.

Subsequently, the source sacrificial layer **104** may be selectively removed through the vertical contact recess **121**. As a result, a horizontal contact recess **123** may be formed. The vertical contact recess **121** and the horizontal contact recess **123** may be coupled to each other. The horizontal contact recess **123** may be formed between the second liner layer **105'** and the first liner layer **103** by removing the source sacrificial layer **104** by a dip-out process. The horizontal contact recess **123** may be parallel to the surface of the lower structure **101**. When the source sacrificial layer **104** is removed, the first and second liner layers **103** and **105'** may remain without being removed due to their etch selectivity. The horizontal contact recess **123** may be formed in the first multi-layer stack **110S**. When the source sacrificial layer **104** is removed, the lower source layer **102** may not be removed. A wet-etch process may be applied to remove the source sacrificial layer **104**. Since the source sacrificial layer **104** includes a polysilicon layer, the wet-etch process may include a chemical capable of etching the polysilicon layer.

A portion of the horizontal contact recess **123** may expose the lower sidewall of the memory stack structure **120P**. The outer wall of the memory stack structure **120P** may be a blocking layer **115**, and the blocking layer **115** of the memory stack structure **120P** may be exposed by the horizontal contact recess **123**. Since the blocking layer **115** includes an oxide, the blocking layer **115** of the memory stack structure **120P** may have an etch selectivity with respect to the source sacrificial layer **104** and thus it may not be etched while the source sacrificial layer **104** is removed. From the perspective of a top view, the horizontal contact recess **123** may be shaped to surround the outer wall of the bottom portion of the memory stack structure **120P**.

Subsequently, the first liner layer **103** may be removed. As a result, the height of the horizontal contact recess **123** may increase in the vertical direction with respect to the orientation of FIG. **20**. The expanded horizontal contact recess **123** may directly contact the lower source layer **102** and the second liner layer **105'**.

While the first liner layer **103** is removed, the blocking layer **115** of the bottom portion of the memory stack structure **120P** may be removed. Thus, the charge trapping

layer **116** of the memory stack structure **120P** may be exposed. A wet-etch process may be applied to remove the first liner layer **103**. The wet-etch process may include a chemical that may selectively remove silicon oxide. While the first liner layer **103** is removed, the second liner layer **105'** may not be removed because it has a wet-etch resistance.

Subsequently, the charge trapping layer **116** in the bottom portion of the memory stack structure **120P** may be removed through the vertical contact recess **121** and the horizontal contact recess **123**. The charge trapping layer **116** may be removed by a wet-etch process. When the charge trapping layer **116** includes a nitride, the wet-etch process may include a chemical capable of etching the nitride.

By removing the charge trapping layer **116**, the horizontal length of the horizontal contact recess **123** may be increased.

Subsequently, the tunnel dielectric layer **117** in the bottom portion of the memory stack structure **120P** may be removed through the vertical contact recess **121** and the horizontal contact recess **123**. The tunnel dielectric layer **117** may be removed by a wet-etch process. When the tunnel dielectric layer **117** includes an oxide, the wet-etch process may include a chemical capable of etching the oxide.

By removing the tunnel dielectric layer **117**, the horizontal length of the horizontal contact recess **123** may be increased.

While the process of removing the source sacrificial layer **104**, the process of removing the first liner layer **103**, the process of removing the blocking layer **115**, the process of removing the charge trapping layer **116**, the process of removing the tunnel dielectric layer **117** are performed as described above, the sacrificial sealing layer **122** may serve as an etch barrier for protecting the dielectric layers **111** and **113** and the sacrificial layer **112**.

The outer wall of the bottom portion of the channel layer **118** of the memory stack structure **120P** may be exposed by the processes of expanding the horizontal contact recess **123**.

The first multi-layer stack in which one or more horizontal contact recesses **123** are formed may be denoted by **110S'**. The remaining second liner layer **105'** may be referred to as a carbon-containing liner layer.

A contact opening penetrating through the first multi-layer stack **110S'** and the second multi-layer stack **120M** may be formed through a series of the processes illustrated in FIGS. **16** to **20**. The contact opening may include a vertical contact recess **121** and a horizontal contact recess **123**. The horizontal contact recess **123** may extend from the vertical contact recess **121**. The vertical contact recess **121** may extend in a direction (e.g., a vertical direction) perpendicular to the surface (e.g., the top surface) of the lower structure **101**, and the horizontal contact recess **123** may extend in a direction (e.g., a horizontal direction) parallel to the surface of the lower structure **101**. The horizontal contact recess **123** may have a high aspect ratio that is parallel to the surface of the lower structure **101**. The vertical contact recess **121** may have a high aspect ratio that is perpendicular to the lower structure **101**.

Subsequently, processes similar to those shown in FIGS. **7** to **14** may be performed over the resulting structure shown in FIG. **20**. Hereinafter, descriptions will be given with reference to FIGS. **21** to **28**.

Referring to FIG. **21**, a source contact material **124A** may be formed to fill a contact opening, e.g., a vertical recess **121** and a horizontal contact recess **123**. The source contact material **124A** may include a conductive material. The source contact material **124A** may include polysilicon. The

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source contact material **124A** may include phosphorus (P)-doped polysilicon. The source contact material **124A** may include carbon-containing polysilicon. The source contact material **124A** may include a stack of phosphorus-doped polysilicon (SiP) and carbon-doped polysilicon (SiC).

Subsequently, the source contact material **124A** may be selectively removed. The selective removal of the source contact material **124A** may include a recessing process, and the recessing process may include a wet-etch process. As a result of performing the wet-etching process on the source contact material **124A**, a source contact layer **124** may be formed in the horizontal contact recess **123**. The source contact layer **124** may partially fill the horizontal contact recess **123**. For example, the source contact material **124A** may be etched such that the source contact layer **124** is self-aligned to the sidewall of the sacrificial sealing layer **122**, and thus the bottom of the vertical recess **121** may directly contact the lower source layer **102**. The source contact layer **124** may remain in the horizontal contact recess **123**, and the source contact layer **124** may not remain in the vertical recess **121**.

Although not illustrated, the source contact layer **124** may subsequently be exposed to an oxidation process. The oxidation process may include dry oxidation or wet oxidation. An edge of the source contact layer **124** may be oxidized by the oxidation process. As a result, a barrier oxide (not shown) may be formed at the edge of the source contact layer **124**. The barrier oxide may include silicon oxide. The barrier oxide may protect the source contact layer **124** from being attacked during the subsequent process.

The first multi-layer stack **110S'** in which the source contact layer **124** is formed may be simply referred to as a source-level stack **110**. The source level stack **110** may be disposed below the second multi-layer stack **120M**, and the source contact layer **124** may be directly coupled to the channel layer **118** of the memory stack structure **120P**.

As described above, the source-level stack **110** which is formed by a series of processes of replacing the source sacrificial layer **104** with the source contact layer **124** may have a structure in which the source contact layer **124** is embedded.

Referring to FIG. **22**, the sacrificial layers **112** of the second multi-layer stack **120M** may be selectively removed. As a result, horizontal gate recesses **125** may be formed between the dielectric layers **111**. Since the sacrificial layer **112** includes nitride, the sacrificial layer **112** may be removed by a chemical including phosphoric acid ( $H_3PO_4$ ). While the sacrificial layer **112** is removed, the sacrificial sealing layer **122** may also be removed at the same time. According to another embodiment of the present disclosure, the sacrificial sealing layer **122** may be removed after the sacrificial layer **112** is removed.

While the sacrificial layer **112** is removed, the source contact layer **124** may be sufficiently protected by a barrier oxide. The barrier oxide may serve as a protective layer for protecting the source contact layer **124** from being attacked.

The horizontal gate recesses **125** may be continuous from the vertical contact recess **121**. Portions of the blocking layer **115** of the memory stack structure **120P** may be exposed by the horizontal gate recesses **125**.

After the horizontal gate recesses **125** are formed in the second multi-layer stack **120M** in FIG. **21**, a first intermediate multi-layer stack **120'** may be formed. The first intermediate multi-layer stack **120'** may have a structure in which the dielectric layers **111** and the horizontal gate recesses **125**

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alternate. The horizontal gate recess **125** may also be formed between the top dielectric layer **113** and the neighboring dielectric layer **111** as well.

Referring to FIGS. **23** and **24**, the gate electrodes **127** may fill the horizontal gate recesses **125**, respectively. In order to form the gate electrodes **127**, a gate material layer **126** may be deposited to fill the horizontal gate recesses **125** (see FIG. **23**). After the gate material layer **126** is formed, a second intermediate multi-layer stack **120''** may be formed. The second intermediate multi-layer stack **120''** may have a structure in which the dielectric layers **111** and the gate material **126** alternate, and the gate material **126** may cover the sidewalls of the vertical contact recesses **121**.

Subsequently, as illustrated in FIG. **24**, the gate electrodes **127** may be formed by performing an etch-back process on the gate material layer **126**. The gate electrodes **127** may include a low resistance material. The gate electrodes **127** may include a metal-based material. The gate electrodes **127** may include a metal, a metal silicide, a metal nitride, or a combination thereof. For example, the metal may include nickel, cobalt, platinum, titanium, tantalum, or tungsten. The metal silicide may include nickel silicide, cobalt silicide, platinum silicide, titanium silicide, tantalum silicide, or tungsten silicide. The gate electrodes **127** may include a stack of titanium nitride and tungsten.

The ends **127R** of the gate electrodes **127** may have a shape that is horizontally recessed from the ends of the dielectric layers **111**. The ends **127R** of the gate electrodes **127** may be exposed by the vertical contact recesses **121**. The gate electrodes **127** may not contact the second liner layer **105'**, the lower source layer **102**, and the source contact layer **124**.

After the gate electrodes **127** are formed, an alternating stack **120** may be formed. The alternating stack **120** may have a structure in which the dielectric layers **111** and the gate electrodes **127** are stacked alternately. The memory stack structure **120P** may penetrate through the alternating stack **120**, and the vertical contact recesses **121** may penetrate through the alternating stack **120**.

The source-level stack **110** may include a lower source layer **102**, a source contact layer **124**, and a second liner layer **105'**, and the bottom portion of the vertical contact recess **121** may not penetrate the lower source layer **102**. Hereinafter, the second liner layer **105'** may be called a carbon-containing liner layer **105'**.

Referring to FIG. **25**, the surface of the vertical contact recesses **121** may be sealed. The surface of the vertical contact recesses **121** may be sealed by a sealing layer **128S**. The sealing layer **128S** may include one or more protrusions **128P**, and the protrusions **128P** may seal the ends **127R** of the gate electrodes **127**. The sealing layer **128S** may seal the sides of the dielectric layers **111** and **113**. The sealing layer **128S** may seal the side of the source contact layer **124**. The sealing layer **128S** may seal the side of the carbon-containing liner layer **105'** and may seal the exposed surface of the lower source layer **102**. The sealing layer **128S** may include a silicon oxide-based material. The sealing layer **128S** may include a low dielectric material. The low dielectric material may have a lower dielectric constant than silicon nitride. The material of the sealing layer **128S** may have a dielectric constant that is lower than approximately 7.

The sealing layer **128S** may be thinner than the dielectric layers **111** and **113** and the gate electrode **127**. The sealing layer **128S** may be a layer of a material that is different from the material of the dielectric layers **111** and **113**. The sealing layer **128S** may be a layer of a material that is different from that of the gate electrode **127**. The sealing layer **128S** may

include a material having a high wet-etch resistance. The wet-etch resistance of the sealing layer 128S may be obtained from carbon. The sealing layer 128S may be formed of a carbon-containing material, and the dielectric layers 111 and 113 may be formed of a carbon-free material. The dielectric layers 111 and 113 may be formed of carbon-free silicon oxide, and the sealing layer 128S may be formed of carbon-containing silicon oxide. For example, the dielectric layers 111 and 113 may be formed of SiO<sub>2</sub> and the sealing layer 128S may be formed of SiCO. SiCO may be more etch-resistant than SiO<sub>2</sub>. The carbon content of SiCO may be less than the silicon content and the oxygen content. For example, SiCO may have a composition ratio of silicon (Si) 34 at %, oxygen 40 at %, and carbon 17 at %. SiCO may have a lower dielectric constant than silicon nitride (Si<sub>3</sub>N<sub>4</sub>).

The sealing layer 128S may be formed to have a thickness of approximately 50 Å to 100 Å. The high wet-etch resistance of SiCO may reduce the thickness of the sealing layer 128S. As a result, the size of each of the vertical contact recesses 121 for separating cell blocks may be reduced, which eventually leads to decreased chip size. In a comparative example, when a sealing layer is formed of SiO<sub>2</sub>, the sealing layer should be formed to have a thickness of approximately 150 Å or thicker in consideration of loss in the subsequent processes (e.g., a cleaning process). The thick SiO<sub>2</sub> sealing layer of the comparative example may make it difficult to fill the vertical contact recesses with source contact plugs without voids, and each of the vertical contact recesses of the comparative example should have a relatively large size in order to improve the gap-fill characteristics of the source contact plugs. On the contrary, since SiCO of the sealing layer 128S according to an embodiment of the present disclosure has a higher wet-etch resistance than SiO<sub>2</sub>, the sealing layer 128S may be formed thinner than the sealing layer of SiO<sub>2</sub> in the comparative example. Therefore, even though the size of the vertical contact recesses 121 is small, the vertical contact recesses 121 may be filled with source contact plugs without voids.

According to another embodiment of the present disclosure, the sealing layer 128S may include a material that is wet-etch resistant with respect to the subsequent processes. The sealing layer 128S may include SiCN, SiBCN, SiBN, or a combination thereof. The wet-etch resistance of the sealing layer 128S may be obtained from carbon, nitrogen, boron, or a combination thereof.

According to another embodiment of the present disclosure, a seed layer may be formed prior to the formation of the sealing layer 128S. The seed layer may form a thin silicon oxide layer or a thin silicon nitride layer. By forming the seed layer, the conformality of the sealing layer 128S may be improved.

According to another embodiment of the present disclosure, the sealing layer 128S may include a stack of one or more carbon-free silicon oxide layers and one or more carbon-containing silicon oxide layers. For example, after thinly depositing a carbon-free silicon oxide layer, a carbon-containing silicon oxide layer may be deposited over the carbon-free silicon oxide layer. The carbon-free silicon oxide may improve the conformality of the carbon-containing silicon oxide as the seed layer.

Referring to FIG. 26, the sealing layer 128S may be selectively removed to expose the surface of the lower source layer 102. As a result, a sealing spacer 128 may be formed on the sidewall of the vertical contact recess 121. The bottom portion of the sealing spacer 128 may substantially completely cover the side of the source contact layer 124 and the side of the carbon-containing liner layer 105'.

The sealing spacer 128 may include one or more protrusions 128P, and the protrusions 128P may seal the ends 127R of the gate electrodes 127. The sealing spacer 128 may seal the sides of the dielectric layers 111 and 113.

The sealing spacer 128 may be vertically continuous along the stacking direction of the dielectric layers 111 and the gate electrodes 127. From the perspective of a top view, the sealing spacer 128 may have a closed loop-shape that seals the sidewalls of the vertical contact recesses 121.

Since the thickness of the sealing layer 128S is thin, the open area of the bottom surface of the vertical contact recess 121 may be increased in an etch process for forming the sealing spacer 128. As a result, it is possible to secure an electrically low resistance and process stability.

After the sealing spacer 128 is formed, a post-cleaning process may be performed.

Referring to FIGS. 27 and 28, the vertical contact recesses 121 may be filled with a conductive contact material. For example, a source contact plug 132 may be formed in each vertical contact recess 121. The source contact plugs 132 may fill the vertical contact recesses 121. Each of the source contact plugs 132 may include a stack of a silicon-containing material 129 and a metal-containing material 131, and it may further include a barrier material 130 between the silicon-containing material 129 and the metal-containing material 131. The silicon-containing material 129 may include polysilicon, and the metal-containing material 131 may include tungsten. The barrier material 130 may include titanium nitride. According to another embodiment of the present disclosure, the source contact plugs 132 may be formed of tungsten alone.

The silicon-containing material 129 may be formed by depositing polysilicon to fill the vertical contact recesses 121 and then performing an etch-back process on the polysilicon. A pre-cleaning process may be performed before the deposition of the polysilicon, and a post-cleaning process may be performed after the etch-back process of the polysilicon. The silicon-containing material 129 may be in contact with the sealing spacer 128.

After the silicon-containing material 129 is formed, the barrier material 130 may be conformally deposited. A pre-cleaning process may be performed before the deposition of the barrier material 130. After the conformal deposition of the barrier material 130, the remainder of the vertical contact recess 121 may be filled with the metal-containing material 131. After the barrier material 130 and the metal-containing material 131 are sequentially deposited, a planarization process using Chemical Mechanical Polishing (CMP) may be performed. As a result, the barrier material 130 and the metal-containing material 131 may remain only inside the vertical contact recess 121. The barrier material 130 may be in direct contact with the sealing spacer 128, and the metal-containing material 131 may not contact the sealing spacer 128.

Although a plurality of cleaning processes are performed during the process of forming the sealing spacer 128, the process of forming the silicon-containing material 129, and the process of depositing the barrier material 130, thickness loss of the sealing spacer 128 may hardly occur.

As described above, the source-level stack 110 and the alternating stack 120 may be formed over the lower structure 101. The source-level stack 110 may include a lower source layer 102, a source contact layer 124, and a carbon-containing liner layer 105'. The alternating stack 120 may be formed by alternately stacking the dielectric layers 111 and the gate electrodes 127. The memory stack structure 120P may completely penetrate through the alternating stack 120 and

may not completely penetrate through the source-level stack **110**. The bottom portion of the memory stack structure **120P** may penetrate through the carbon-containing liner layer **105'** and the source contact layer **104** of the source-level stack **110**, but may not penetrate through the lower source layer **102**. The outer wall of the bottom portion of the channel layer **118** of the memory stack structure **120P** may directly contact the source contact layer **124**. The channel layer **118**, the lower source layer **102**, and the source contact plug **132** may be electrically connected through the source contact layer **124**.

The gate electrodes **127** and the source contact plug **132** may be electrically disconnected by the sealing spacer **128**. The gate electrodes **127** and the source contact plug **132** may be physically disconnected by the sealing spacer **128**. A high voltage may be repeatedly applied between the gate electrode **127** and the source contact plug **132**, which increases GBB. This is called a Grown Bad Block phenomenon. According to the embodiment of the present disclosure, the GBB defects may be prevented by forming the sealing spacer **128** including a carbon-containing material. In other words, since the sealing spacer **128** is formed of a material having a high wet-etch resistance, thickness loss of the sealing spacer **128** may not substantially occur during the subsequent cleaning processes. Thus, the sealing spacer **128** may be formed thick enough to withstand the high voltage applied between the gate electrode **127** and the source contact plug **132**.

Also, since the sealing spacer **128** is formed of a low dielectric material, the parasitic capacitance between the gate electrodes **127** and the source contact plugs **132** may be reduced.

Also, according to an embodiment of the present disclosure, since the carbon-containing liner layer **105'** is formed of SiCO, there is no significant thickness loss by a wet-etch chemical, and the thickness loss of SiCO caused during the process of forming the horizontal contact recesses **123** and the process of expanding the horizontal contact recesses **123** (i.e., a dry etch process and a wet-etch process for removing the blocking layer **115**, the charge trapping layer **116**, and the tunnel dielectric layer **117**) is so small that the breakdown voltage (BV) characteristics with the source contact plugs **132** may be improved.

In addition, when the carbon-containing liner layer **105'** is formed of SiCO, the bottom dielectric layer **111** may be formed relatively thin (e.g., approximately 200 Å). Thus, the dopant diffusion movement distance from the source contact layer **124** to the channel layer **118** adjacent to the bottom gate electrode **127** may be shortened. As shown in FIG. 2, when the stack of the second liner layer **105** and the upper source layer **106** is applied, the dopant diffusion movement distance may be approximately 450 Å (the bottom dielectric layer of approximately 300 Å+the upper source layer of approximately 150 Å). In contrast, when only the second liner layer **105'** is applied, the dopant diffusion movement distance may be approximately 300 Å (the bottom dielectric layer **111** of approximately 200 Å+the second liner layer **105'** of approximately 100 Å).

Referring to FIGS. 16 to 28, a method for fabricating a vertical semiconductor device may include: forming a first multi-layer stack **110S** that includes a sacrificial source layer **104** and a carbon-containing liner layer **105'** over a lower structure **101**; forming a second multi-layer stack **120M** in which dielectric layers **111** and sacrificial layers **112** are alternately stacked over the first multi-layer stack **110S**; forming a memory stack structure **120P** that includes a channel layer **118** extending to penetrate through the second

multi-layer stack **120M** and the first multi-layer stack **110S**; forming a vertical contact recess **121** extending to penetrate through the second multi-layer stack **120M** and the first multi-layer stack **110S** by being spaced apart from the memory stack structure **120P**; forming a horizontal contact recess **123** by selectively removing the sacrificial source layer **104** through the vertical contact recess **121**; expanding the horizontal contact recess **123** to expose the lower outer wall of the channel layer **118**; filling the extended horizontal contact recess **123** with the source contact layer **124**; replacing the sacrificial layers **112** with the gate electrodes **127**; forming a sealing spacer **128** that seals sidewalls of the vertical contact recess **121** over the source contact layer **124** and the gate electrodes **127**; and forming a source contact plug **132** in the vertical contact recess **121**. The carbon-containing liner layer **105'** and the sealing spacer **128** may be formed of carbon-containing silicon oxide.

Carbon-containing silicon oxide, i.e., SiCO, may be applied to the process of forming contact plugs in DRAMs, logic devices, and the like. For example, after contact etch process for forming a contact hole in an inter-layer dielectric layer is performed, a SiCO spacer may be formed on the sidewall of the contact hole by depositing SiCO and performing an etch-back process. After the SiCO spacer is formed, the contact hole may be filled with a conductive contact plug. The SiCO spacer may be exposed to a plurality of cleaning processes such as a post-cleaning after the SiCO spacer is formed, a post-cleaning before the conductive contact plug is formed, and the like. Even though the SiCO spacer is exposed to the subsequent cleaning processes, since the SiCO spacer is a material with a high wet-etch resistance, there may be little thickness loss.

According to embodiments of the present disclosure, electrical characteristics may be improved as a sealing spacer is formed of a material having a high wet-etch resistance between the gate electrodes and the source contact plugs.

According to embodiments of the present disclosure, it is possible to form a sealing spacer to be thick enough to withstand the high voltage applied between a gate electrode and a source contact plug.

According to embodiments of the present disclosure, since a sealing spacer is formed of a low dielectric material, the parasitic capacitance between the gate electrodes and the source contact plugs may be reduced.

According to embodiments of the present disclosure, reliability of a vertical semiconductor device may be improved.

While the present disclosure has been described with respect to the specific embodiments, it will be apparent to those skilled in the art that various changes and modifications may be made without departing from the spirit and scope of the disclosure as defined in the following claims.

What is claimed is:

1. A method for fabricating a semiconductor device, comprising:
  - forming a first multi-layer stack including liner layers and a source sacrificial layer over a lower structure;
  - forming a second multi-layer stack including dielectric layers and sacrificial layers over the first multi-layer stack;
  - forming a vertical contact recess extending through the second multi-layer stack and the source sacrificial layer;

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replacing the source sacrificial layer with a source contact layer;

replacing the sacrificial layers with conductive layers;  
forming a seed layer on a sidewall of the vertical contact recess to seal the conductive layers;

forming a carbon-containing spacer on the seed layer; and  
forming a source contact plug in the vertical contact recess.

2. The method of claim 1, wherein the carbon-containing spacer includes a material having a wet-etch resistance greater than that of the dielectric layers.

3. The method of claim 1, wherein the carbon-containing spacer includes a carbon-containing silicon oxide.

4. The method of claim 1, wherein the carbon-containing spacer includes a material that has a wet-etch resistance greater than that of SiO<sub>2</sub> and a dielectric constant lower than that of silicon nitride.

5. The method of claim 1, wherein the carbon-containing spacer includes SiCO, and a carbon content of SiCO is less than a silicon content and an oxygen content.

6. The method of claim 1, wherein the carbon-containing spacer is disposed between the conductive layers and the source contact plug, and extend in a stack direction of the conductive layers and the dielectric layers to seal one or more ends of the conductive layers.

7. The method of claim 1, further comprising:  
forming a lower source layer over the lower structure;  
forming a first liner layer over the lower source layer;  
forming a second liner layer over the source sacrificial layer; and

forming an upper source layer over the second liner layer, wherein the source sacrificial layer disposed between the first liner layer and the second liner layer, and

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wherein the second multi-layer stack disposed on the upper source layer.

8. The method of claim 7, wherein the first liner layer, or the second liner layer, or both include a silicon oxide or a carbon-containing silicon oxide.

9. The method of claim 7, wherein the first liner layer includes a silicon oxide, and the second liner layer includes a carbon-containing silicon oxide.

10. The method of claim 1, further comprising:

forming a lower source layer over the lower structure;  
forming a first liner layer over the lower source layer; and  
forming a second liner layer over the source sacrificial layer,

wherein the source sacrificial layer disposed between the first liner layer and the second liner layer,  
wherein the second multi-layer stack disposed on the second liner layer, and

wherein the first liner layer is formed of a silicon oxide, and the second liner layer is formed of SiCO.

11. The method of claim 1, wherein the seed layer includes silicon oxide layer or silicon nitride.

12. The method of claim 1, wherein the dielectric layers are formed of carbon-free silicon oxide, and the carbon-containing spacer is formed of carbon-containing silicon oxide.

13. The method of claim 1, wherein the carbon-containing spacer includes one or more protrusions extending to seal one or more ends of the conductive layers, respectively.

14. The method of claim 1, wherein the carbon-containing spacer is formed between the seed layer and the source contact plug.

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